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FINAL CHARACTERIZATION OF TRICHLOROETHENE PLUME AT AIR FORCE PLANT 4

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NAVAL AIR STATION
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FINAL REPORT

Characterization of Trichloroethene Plume Air Force Plant 4 and Carswell Air Force Base Fort Worth, Texas

Prepared for:

U.S. Army Engineer District
Ft. Worth, Texas

July 1994

Prepared by:

ESE Environmental Science & Engineering, Inc.
A CILCORP Company

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LIST OF ACRONYMS AND ABBREVIATIONS

AFP4	Air Force Plant 4
CAFB	Carswell Air Force Base
°	degrees
1,2-DCE	1,2-dichloroethene
DNAPL	dense, nonaqueous-phase liquid
DOD	U.S. Department of Defense
DP12	Chrome Pit No. 3
EPA	U.S. Environmental Protection Agency
ESE	Environmental Science & Engineering, Inc.
FDTA 2	Fire Department Training Area No. 2
FFA	Federal Facilities Agreement
FR	Federal Register
FS	feasibility study
ft/ft	feet per foot
ft/day	feet per day
ft	foot
ft^2/day	square feet per day
g/cm^3	grams per cubic centimeter
GD	General Dynamics
GOCO	government-owned/contractor-operated
gpd	gallons per day
gpd/ft	gallons per day per foot
HM	Hargis & Montgomery, Inc.
IRP	Installation Restoration Program
K_{oc}	carbon/water coefficient
LF03	Landfill No. 3
LF04	Landfill No. 4
LF05	Landfill No. 5

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued, Page 2 of 2)

LNAPL	light nonaqueous-phase liquid
mg/L	milligrams per liter
NPL	National Priorities List
PA/SI/RI	preliminary assessment/site inspection/remedial investigation
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
SOW	scope of work
TCE	trichloroethene
TWC	Texas Water Commission
μg/L	micrograms per liter
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force
VOC	volatile organic compound

1.0 INTRODUCTION

This draft report was prepared by Environmental Science & Engineering, Inc. (ESE) under the U.S. Army Corps of Engineers (USACE) Contract Number DACW63-93-D-011, Delivery Order No. 3 entitled "Feasibility Study and Recommendations for Remediation of the Trichloroethene (TCE) Plume, Carswell Air Force Base and Air Force Plant No. 4, Fort Worth, Texas." Delivery Order No. 3 consists of seven separate tasks. This report specifically addresses the requirements of Task 3, Characterization of the TCE Plume within the Study Area (1.C.1 and 1.C.2).

1.1 SCOPE OF WORK (SOW)

The scope of this report involved completion of a TCE plume characterization report based on available data collected during previous work completed during the first two tasks of this contract. ESE was tasked to complete the following objectives:

1. Provide a geologic and hydrogeologic setting and conditions beneath Carswell Air Force Base (CAFB) and Air Force Plant 4 (AFP4);
2. Describe the horizontal and vertical extent of the TCE plume in the soil and groundwater underlying CAFB and AFP4;
3. Describe the concentration of TCE vertically and horizontally within the plume;
4. Provide the probable time and rate of plume migration without remediation, including location, size, shape, and concentrations at distinct future times using relatively simple techniques for prediction; and
5. Provide recommendations for and descriptions of any additional studies necessary to provide the required information and/or to validate assumptions and/or conclusions.

ESE was also tasked to present graphics appropriate for the TCE plume characterization report.

Additionally, ESE fulfilled these requirements with respect to two additional volatile organic compounds (VOCs) for the most recent sampling period. This report describes the vertical and horizontal extent of 1,2-dichloroethene (1,2-DCE) and vinyl chloride contamination present in the upper aquifer system and the Paluxy aquifer. Degradation products of TCE (1,2-DCE and vinyl chloride) were included in the TCE characterization report to provide the information necessary to complete a comprehensive feasibility study (FS) for this study area (Task 5).

1.2 SITE HISTORY--AFP4

AFP4, a government-owned/contractor-operated (GOCO) facility, encompasses 602 acres in Tarrant County Texas, 7 miles west of the center of Fort Worth (Figure 1-1). The plant is bordered on the north by Lake Worth, the east by CAFB, the south and west by the community of White Settlement. AFP4 shares a runway and several facilities with CAFB. AFP4 is an aircraft manufacturing plant currently operated by Lockheed. The facility has been in operation since 1942 and currently produces F-16 aircraft, missile components, radar units, and various other aircraft.

Historically, the manufacturing processes at AFP4 have generated an estimated 5,500 to 6,600 tons of waste oils, solvents, paint residues, and spent process chemicals per year. The wastes were disposed of onsite in landfills, treated via onsite incineration, or discharged into pits or sanitary sewer system. A waste treatment plant was constructed in the early 1970s to treat process wastes, rinse waters, other wastewater, and solvents. Some wastes, such as paint residues and process cyanide solutions, were disposed of offsite by a contractor, but other wastes, including waste oils and fuels, continued to be disposed of in onsite landfills or burned in fire training exercises. During the late 1970s, the burning

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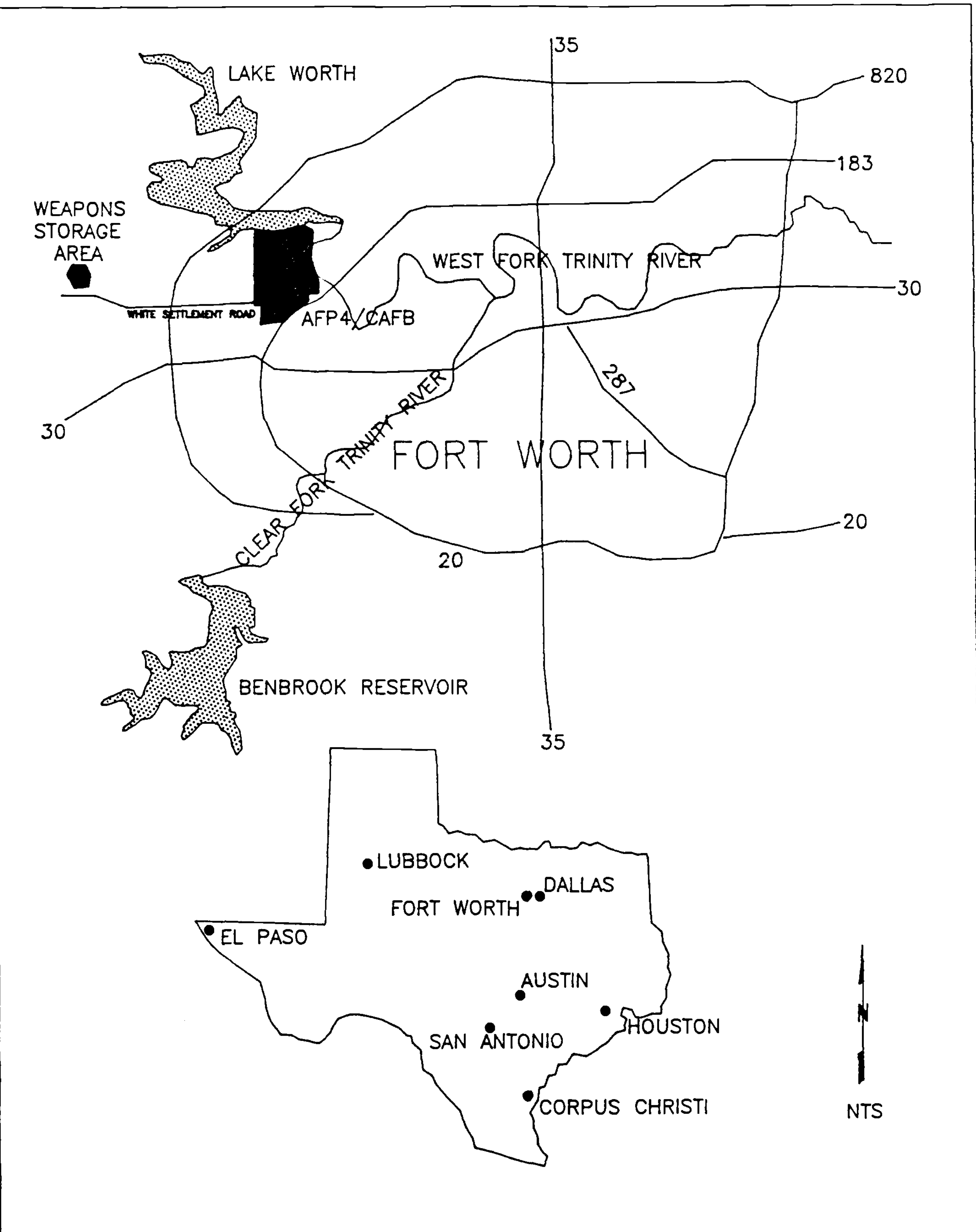

CAFB–AFP4 SITE LOCATION MAP
AIR FORCE PLANT 4 / CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 1–1

Source : ESE, 1994

Project No. :	3932033G-0310
Date :	February 1994
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of fuels for fire training was phased out, and all waste oils and recoverable solvents have since been disposed of offsite by the contractor. Currently, through waste minimization techniques, the offsite disposal of wastes is less than 2,500 tons per year.

Potential contamination at AFP4 was first noticed by a private citizen in September 1982. General Dynamics (GD) (the former contractor at the plant) took immediate action. The contamination was determined to be leachate from Landfill No. 3 (LF03). GD conducted a subsurface investigation to characterize subsurface conditions beneath the plant. The Phase I investigation of subsurface conditions, performed by Hargis & Montgomery, Inc. (HM), was completed in February 1983. The Phase I investigation confirmed the presence of groundwater contamination in the Terrace Deposits flow system. The contamination primarily consisted of metals and VOCs (TCE and TCE degradation products). The investigation confirmed the presence of VOC contamination in the underlying Paluxy aquifer and a possible breach in the confining layer between the Terrace Deposits flow system and the Paluxy aquifer.

Since the recognition of initial contamination, numerous subsurface assessments and investigations have been conducted at AFP4 to characterize the groundwater contamination. The U.S. Department of Defense (DOD) has taken actions to locate and identify past disposal sites and eliminate the resultant potential contaminant hazards to public health in an environmentally sound manner via the Installation Restoration Program (IRP) (Intellus, 1986).

The IRP for AFP4 was initiated in March 1984 with the completion of a records search. At the time of the record search, 20 disposal sites were identified by the contractor performing the work. On October 15, 1984, AFP4 was proposed for inclusion on the National Priorities List (NPL) [49 Federal Register (FR) 40320]. The second phase of the IRP, the confirmation/quantification study, was completed in December 1987. The Phase II study confirmed the presence of groundwater contamination, consisting primarily of VOC contamination, including TCE and TCE degradation products, in the Terrace Deposits flow system and the Paluxy aquifer. The Phase II report included additional probable sources, disposal sites, and areas of concern. On September 4, 1990, the U.S. Air Force (USAF), the U.S. Environmental Protection Agency (EPA) Region VI, and the Texas Water Commission (TWC) signed a Federal Facilities Agreement (FFA). A total of 21 FFA sites, 9 additional IRP sites (not included in the FFA), and 2 areas of concern were outlined for further remedial investigation. The preliminary assessment/site inspection/remedial investigation (PA/SI/RI) was completed in December 1992; however, the downgradient extent of groundwater contamination was not determined.

1.3 SITE HISTORY--CAFB

CAFB was selected for closure and property disposal during round II Base Closure Commission deliberations. The base was transferred to the Navy on October 31, 1993; however, within this report, the site will still be referred to as CAFB.

CAFB is located on 2,751 acres of land in Tarrant County, Texas, approximately 6 miles northwest of Fort Worth. CAFB is bordered on the east by the West Fork of the Trinity River and the community of River Oaks, the north by Lake Worth, the west by AFP4, and the south by the community of White Settlement. Offbase facilities include the ILS marker beacon west of CAFB and the weapons storage area located 4 miles west of CAFB.

Waste was generated and disposed of at CAFB since the beginning of industrial operations in 1942. Major industrial operations included maintenance of jet engines, aerospace equipment, fuel systems, and pneumatic systems, and general and special purpose vehicles, as well as aircraft corrosion control and nondestructive inspection activities. The generated waste was primarily oils, lubricants, recoverable fuels, spent solvents and cleaners. DOD has taken actions to locate and identify past disposal sites and eliminate the resultant potential contaminant hazards to public health in an environmentally sound manner via the IRP. The IRP was initiated at CAFB in 1984 and began with a records search. These studies focused on identifying and characterizing waste disposal areas on the installation.

CAFB currently has 20 IRP sites. Phase I of the IRP identified 15 past disposal sites requiring further IRP action. During Phase II of the IRP, the quantification/confirmation study, five additional sites were added to the CAFB IRP list. Of the 20 current IRP sites at CAFB, 13 are also Resource Conservation and Recovery Act (RCRA) solid waste management sites.

The remedial investigation/feasibility study (RI/FS) Stage I and Stage II conducted during the IRP identified groundwater contamination, consisting primarily of VOCs in the Terrace Deposits flow system underneath the Flightline Area. The main VOC detected consisted of TCE and TCE degradation products. The probable sources of contamination in this area are Landfill No. 4 (LF04) and Landfill No. 5 (LF05), the Waste Burial Area, and Fire Department Training Area No. 2 (FDTA 2). Groundwater samples collected from monitor wells constructed upgradient from this area also contained the same VOC contaminants, proving the existence of an offbase source of groundwater contamination.

2.0 GEOLOGIC SETTING

2.1 REGIONAL GEOLOGY

The upper subsurface in the Tarrant County area is comprised of consolidated sedimentary rocks to unconsolidated sediments that range in age from late Paleozoic to Recent. The Paleozoic rocks include a 6,000- to 7,000-foot (ft) thick section of undifferentiated Pennsylvanian quartzitic sandstone and limestone.

The Paleozoic rocks are unconformably overlain by an alternating section of Lower Cretaceous clastics and carbonates (primarily carbonates) that comprise the Comanche Series and the Gulf Series. The Comanche is divided, in ascending order, into the Trinity, Fredericksburg, and Washita Groups. The Gulf Series includes the Woodbine Formation and the Eagle Ford Shale. The Trinity Group includes, in descending order, the Paluxy, Glen Rose, and Twin Mountains formations. The Paluxy Formation forms the bed of Lake Worth and consists of sandstone and siltstone interbedded with sandy to silty, calcareous, waxy clay and shale. The Paluxy ranges in thickness from 140 to 190 ft across the area. Conformably underlying the Paluxy Formation is the Glen Rose Formation. The Glen Rose consists of sandstone, clay, sandy clay, limestone, and anhydrite, and averages approximately 250 ft in thickness across the area. The Twin Mountains Formation conformably underlies the Glen Rose Formation. The Twin Mountains grades upward from a basal conglomerate of chert and quartz to a fine- to coarse-grained sandstone interbedded with shale and clay. The Twin Mountains Formation averages approximately 250 ft thick across the area and increases in thickness gradually from west to east.

The rocks of the Fredericksburg Group include, in ascending order, the Walnut Formation, the Goodland Limestone, and the Kiamichi Formation. The Walnut Formation is comprised of interbedded brown sandy clay, thinly bedded, fossiliferous clay, fissile shale, and iron-stained earthy limestone. The Walnut ranges in thickness from 0 to 130 ft. The Goodland Limestone consists of white, chalky, fossiliferous, thinly to massively bedded, resistant limestone, and gray to yellow-brown silty marl. The unit ranges from 0 to 30 ft in thickness across the area. The Kiamichi Formation is comprised of blue and brown-yellow marl with thin beds of limestone and sandstone. The formation ranges from 0 to 40 ft in thickness across the area.

The rocks of the Washita Group include, in ascending order, the Duck Creek Formation, Fort Worth Limestone, Denton Clay, Weno Clay, Pawpaw Formation, Main Street Limestone, and Grayson Shale. The Duck Creek Formation consists of gray, aphanitic, fossiliferous limestone that varies in thickness from 30 to 100 ft across the area. The Fort Worth Limestone is represented by alternating layers of fossiliferous limestone and marl. The unit ranges in thickness from 0 to 35 ft across the area. The Denton Clay is comprised of blue-gray marl and includes a shell conglomerate in the upper portion. The unit ranges in thickness from 0 to 35 ft across the area. The Weno Clay includes blue-gray fossiliferous marl and limestone that ranges in thickness from 0 to 75 ft across the area. The Pawpaw Formation is comprised of red-brown shale and ranges from 0 to 40 ft in thickness. The Main Street Limestone is comprised of hard, white, limestone and marl. The unit measures anywhere from 0 to 45 ft in thickness across the area. The uppermost unit within the Washita Group is the Grayson Shale, a yellow-brown to blue-gray fossiliferous marl, clay, and limestone that ranges from 0 to 85 ft in thickness across the area.

The Woodbine Formation of the Gulf Series includes, in ascending order, the Dexter Member and the Louisville Member. The Dexter Member is comprised of fine-grained sandstone, clay, and sandy clay. The unit ranges in thickness from 0 to 110 ft across the area. The Louisville Member is comprised of sandstone, clay, and sandy clay, with minor percentages of lignite and gypsum. The unit ranges from 0 to over 200 ft in thickness. The Woodbine is conformably overlain by the

Eagle Ford Shale. This unit is comprised of blue-black shale and thin-bedded sandstone and limestone. The unit ranges in thickness from 0 to 200 ft.

The Cretaceous rocks are unconformably overlain by Holocene epoch floodplain deposits and Pleistocene epoch terrace deposits. The floodplain deposits consist of alluvium (i.e., gravel, sand, silt, silty clay, and organic material) that fills the stream and river valleys. The base of the flood deposits are marked by a gravel zone of variable thickness. The terrace deposits consist of gravel, sand, and silt, which represent older floodplain deposits.

Table 2-1 provides a summary of the stratigraphic nomenclature and description of the pertinent characteristics of the stratigraphic units in the Tarrant County area.

2.2 SITE-SPECIFIC GEOLOGY

2.2.1 STRATIGRAPHY

Lithologic data collected during the various assessment programs conducted at the subject facilities over the past decade have characterized the uppermost geologic units. The units that have been penetrated by soil borings and/or monitor wells in the area are, from youngest to oldest, as follows:
(1) Quaternary alluvium (including fill material) and Pleistocene terrace deposits,
(2) Cretaceous Goodland Limestone, (3) Cretaceous Walnut Formation,
(4) Cretaceous Paluxy Formation, (5) Cretaceous Glen Rose Formation, and
(6) Cretaceous Twin Mountains Formation. Figure 2-1 presents a generalized geologic section showing the stratigraphic relationships of these rock formations. Figure 2-2 shows the areal limits of these units as they occur at the surface within the study area.

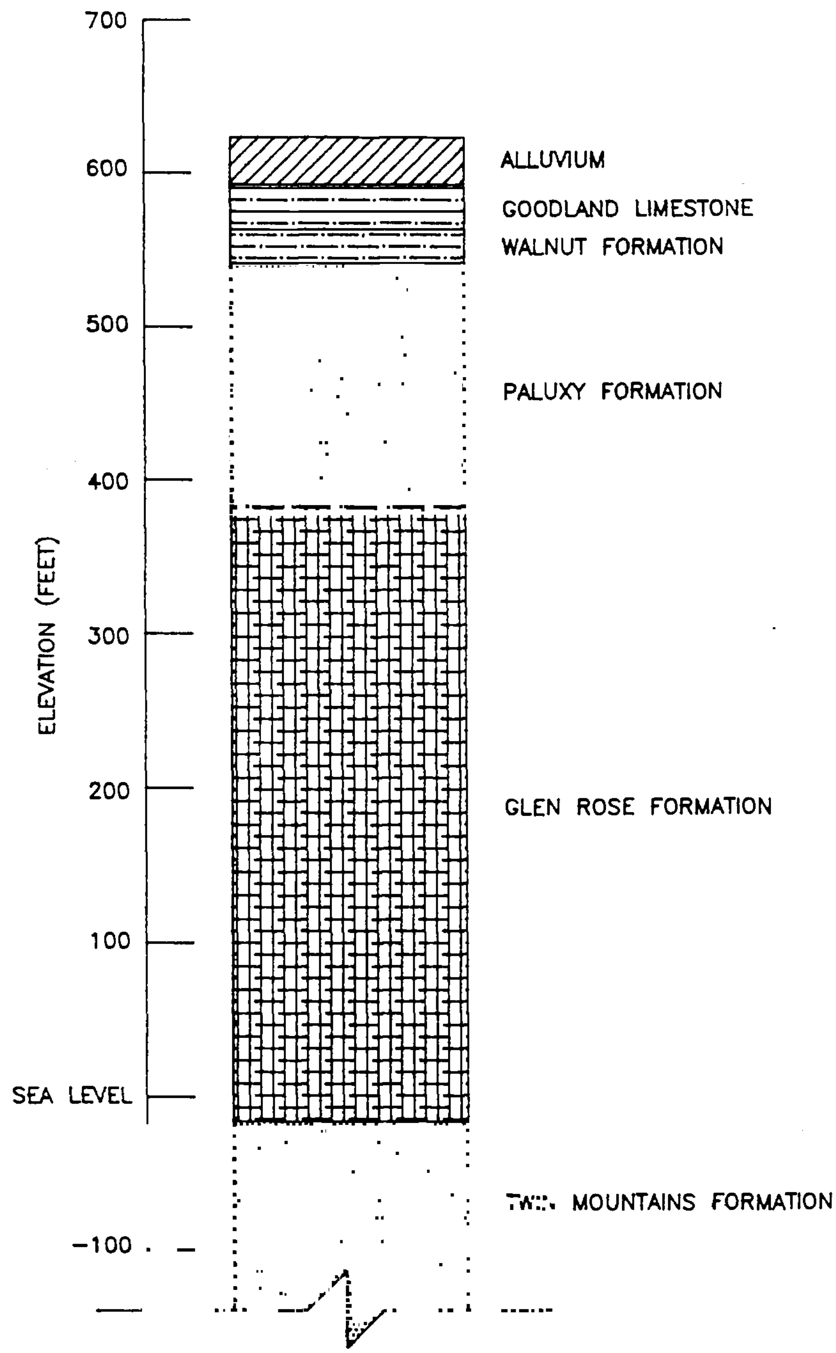
2.2.1.1 Alluvium, Terrace Deposits, and Fill Material

The surface across the site is covered by a veneer of unconsolidated terrace alluvial materials that are comprised of poorly to moderately sorted gravel, sand,

Table 2-1. Stratigraphy of the Tarrant County Area

Era	System	Series/ Group	Stratigraphic Unit	Thick. (ft)	Lithologic Characteristics
Cenozoic	Quaternary	Holocene	Fill Material Alluvium	0-20 0-50	Gravel, sand, silt, clay. Construction debris (fill).
		Pleistocene	Terrace Deposits	0-100	Gravel, sand, and silt.
Mesozoic	Cretaceous	Gulf	Eagle Ford Shale	0-200	Blue-black shale, thin-bedded sandstone and limestone.
			<u>Woodbine Formation</u> Louisville Member	0-200+	Sandstone, clay, and sandy clay.
			Dexter Member	0-110	Fine-grained sandstone, clay, and sandy clay.
		Comanche/ Washita	Grayson Shale	0-85	Yellow-brown to blue-gray marl, clay, and limestone.
			Main Street Limestone	0-45	Hard, white limestone and marl.
			Pawpaw Formation	0-40	Red-brown shale.
			Weno Clay	0-75	Blue-gray marl and limestone.
			Denton Clay	0-35	Blue-gray marl, shell conglomerate in upper portion.
			Fort Worth Limestone	0-35	Alternating layers of fossiliferous limestone and marl.
			Duck Creek Formation	0-90	Blue fossiliferous limestone and marl.
		Comanche/ Fredericksburg	Kiamichi Formation	0-40	Blue and brown-yellow marl with thin beds of limestone and sandstone.
			Goodland Limestone	0-130	White, fossiliferous limestone and blue-yellow marl.
			Walnut Formation	0-28	Shell agglomerate, fossiliferous clay and limestone, sandy clay, and black shale.
		Comanche/ Trinity	Paluxy Sand	140-190	Fine-grained sand, shale, sandy shale, and lignite.
			Glen Rose Limestone	250-450	Fine-grained limestone, shale, marl, and sandstone.
			Twin Mountains Formation	250-450	Coarse- to fine-grained sandstone, red shale, and red to yellow clay at the base.
Paleozoic	Pennsylvanian		Undifferentiated	6,000-7,000	Gray sandy shale, quartzitic sandstone, and black limestone.

Source: Radian Corporation, 1986.



GENERAL GEOLOGIC SECTION IN TARRANT COUNTY AREA
AIR FORCE PLANT 4 / CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 2-1

Source : ESE, 1994

Project No.	39320336-0310
Date	February 1994
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Approved By	M.J.G.

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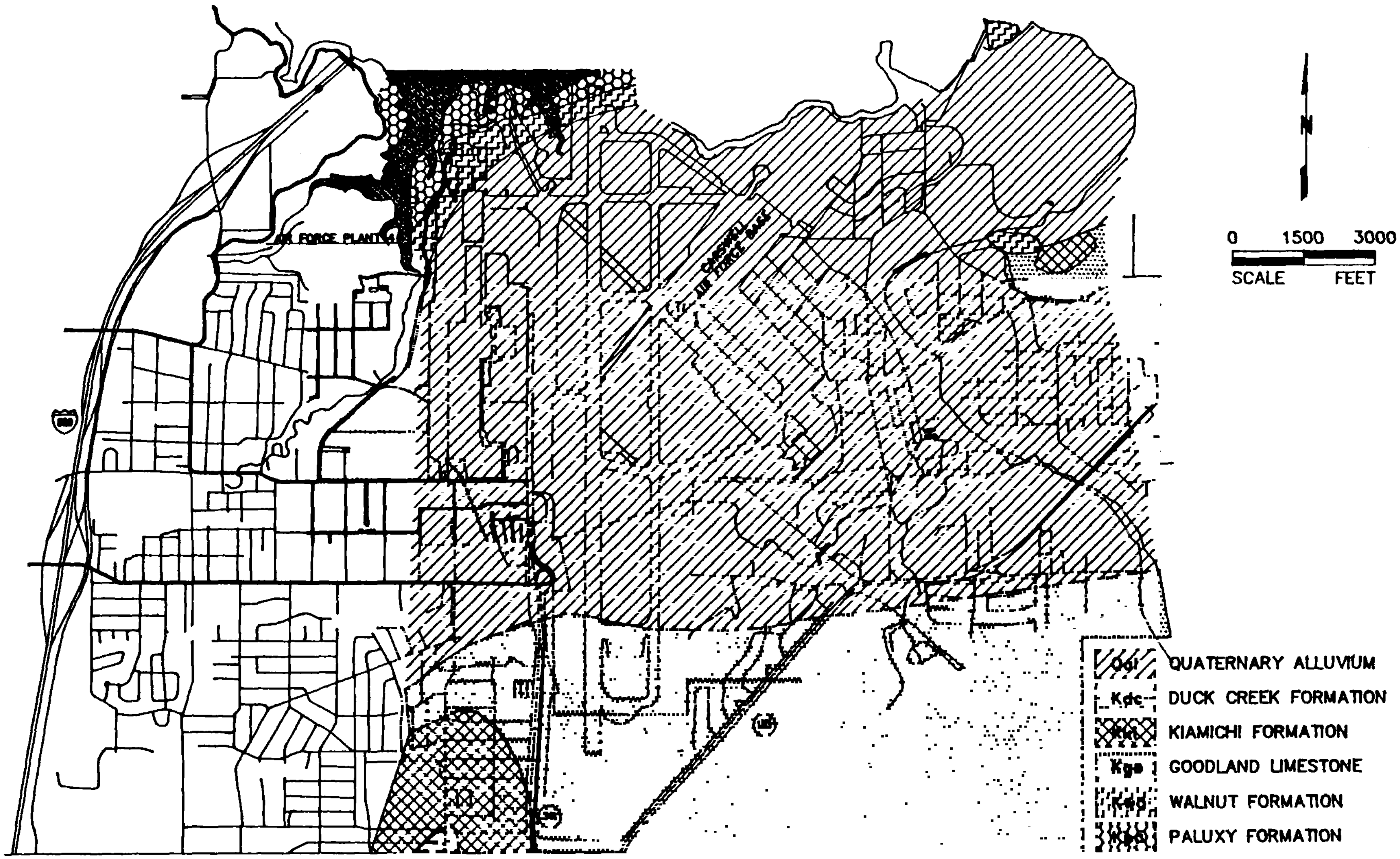
F:\..\OTISMAN\39320330\FIG2-2.DWG



GEOLOGIC MAP
AIR FORCE PLANT 4 / CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 2-2

Source : ESE, 1994

Project No. :39320330-0310
Date :February 1994
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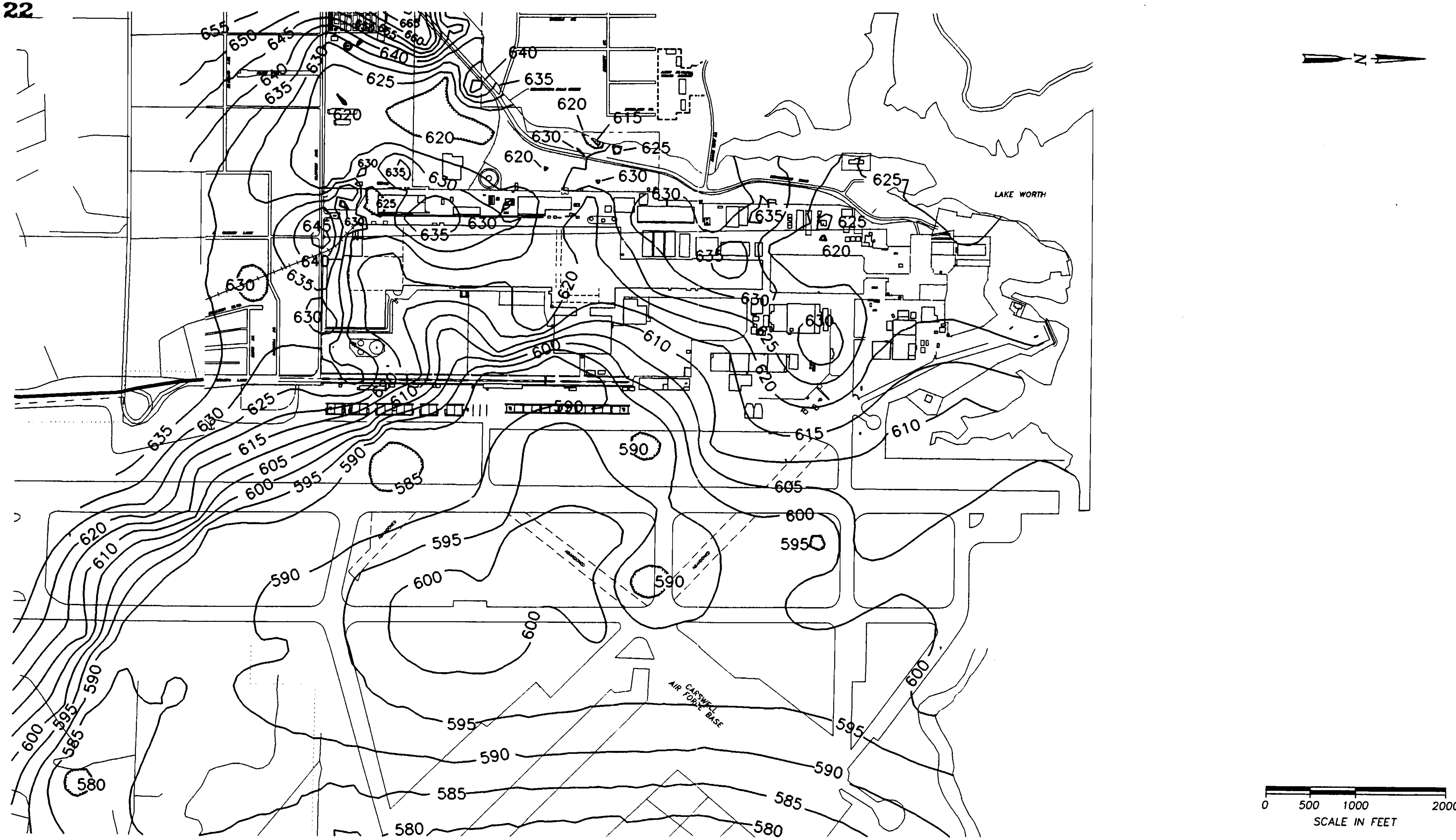
silt, and clay. Individual beds are not laterally continuous. The Quaternary alluvium occurs downstream from the Lake Worth dam in the current floodplain of the West Fork of the Trinity River. Older alluvial and Pleistocene terrace deposits cover most of the nearly flat surface that tilts eastward, perpendicular to the direction of the general strike of the rocks in the area. The base of the alluvium is marked by a zone of gravel of varying thickness. These deposits pinch out to the east at the floodplain of the West Fork of the Trinity River. The fill material occurs in the abandoned landfills, waste pits, and excavated areas, as well as where the land surface was graded during construction activities. In some areas, the fill material extends to the bedrock (marked by the upper surface of the Goodland Limestone beneath most of the area) (HM, 1989).

The thickness of the terrace deposits varies across the study area. They reach a maximum thickness of approximately 60 ft beneath the East Parking Lot and pinch out along the west edge of the AFP4 property (HM, 1989). The variations in thickness reflect the changes in relief along the upper surface of the underlying bedrock in that the deposits are thickest where troughs exist in the upper surface of the Goodland/Walnut units and are thinnest where mounds exist. Figure 2-3 portrays the general configuration of the base of the terrace deposits, which marks the upper surface of the underlying bedrock.

2.2.1.2 Goodland Limestone

The Goodland Limestone is present throughout most of the subsurface within the study area. It is exposed in isolated areas along the south and southwest parts of the AFP4 and CAFB properties. Samples collected in the area indicate that the Goodland Limestone is represented by a chalky-white, fossiliferous, dense, thinly to massively bedded limestone interbedded with gray to yellow-brown stiff clay and marl. The formation forms prominent escarpments along stream cuts.

The upper surface of the unit is highly weathered in places because of its exposure prior to the deposition of the overlying terrace deposits. The formation



SOURCE: CN GEOTECH, 1993.

TOPOGRAPHY OF COMPETENT BEDROCK
AIR FORCE PLANT 4/CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 2-3

Project No.: 3932033G-0320-3120	
Date: March 1994	
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reaches a maximum thickness in the study area of 45 to 50 ft beneath the west side of AFP4 (HM, 1989). The Goodland is continuous throughout the subsurface of the study areas, except in those areas where it has been significantly eroded. The areas with the highest degree of erosion are those where scouring occurred along the bottom of the paleochannels of the West Fork of the Trinity River. Lithologic evidence has identified three paleochannels during the recent investigations (Figure 2-3). One channel is located beneath the southern end of the Assembly Building at AFP4 and extends northeastward to beneath the East Parking Lot, and then southeastward to beneath the Flightline Area at CAFB. At that point, the channel appears to diverge with the main channel extending for an unknown distance southeastward. The second channel extends northward from the radar range to beneath LF02 at AFP4. A third channel is less pronounced and extends northward from Building 152 toward the North Parking Lot. The Goodland has been completely eroded through at several points along these channels (HM, 1989).

2.2.1.3 Walnut Formation

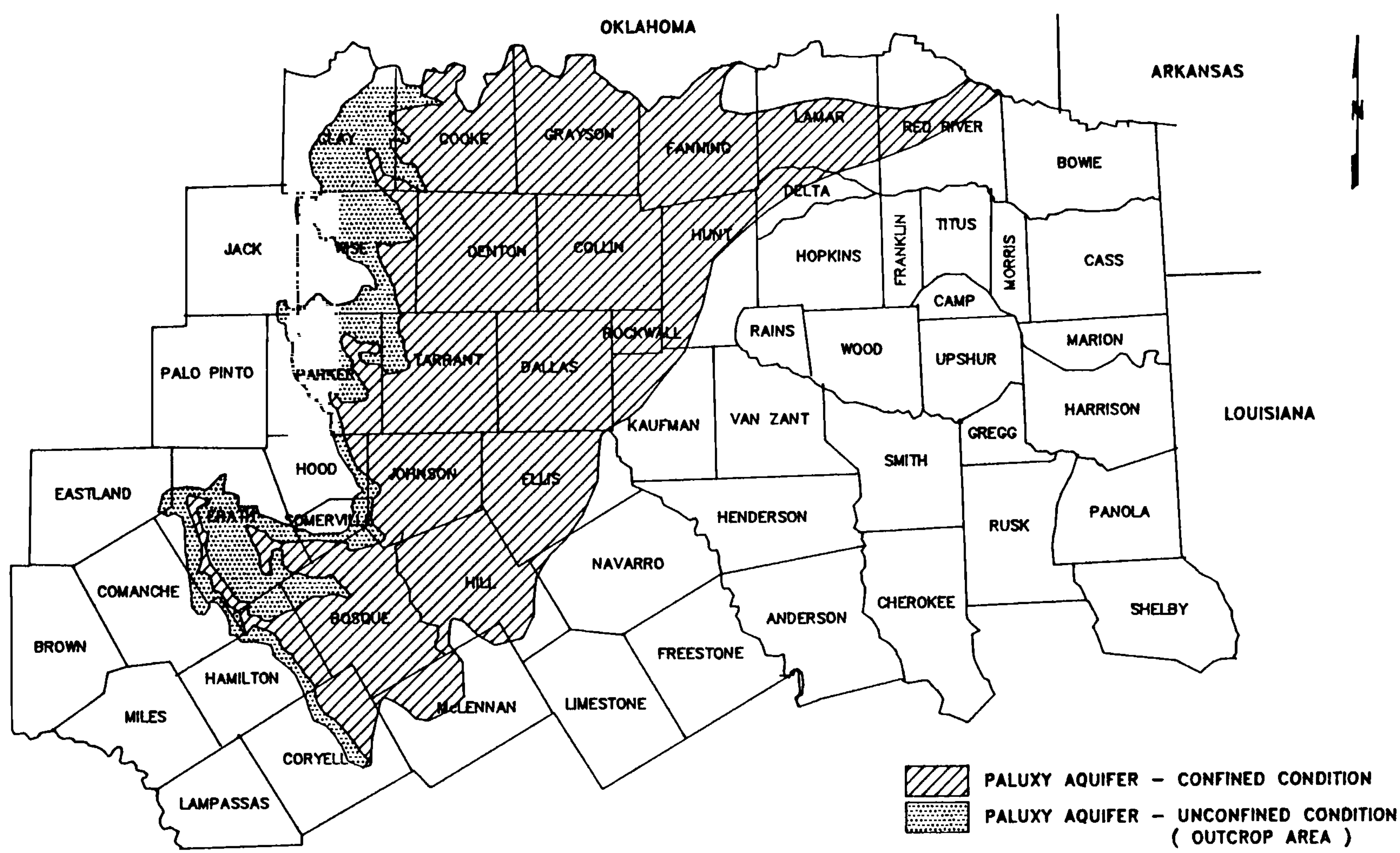
The Walnut Formation is present throughout most of the subsurface beneath the study area. The Walnut Formation is represented by a shell agglomerate limestone, or coquinite, with varying amounts of clay and shale. Dense sandy limestone, silty shale, and minor pyrite also occur in the lower part of the formation. The formation crops out in the low cliffs along the Lake Worth shore and along Meandering Creek Road west of AFP4. The Walnut retains a constant thickness of 25 to 30 ft beneath most of the study area. As with the Goodland rocks, the Walnut Formation has also been seriously eroded along the paleochannels of the Trinity River. As with the overlying Goodland Limestone, the Walnut rocks are also believed to have been completely eroded through in areas where erosion was the most severe. In these areas, the alluvial and terrace deposits are in direct contact with the rocks of the underlying Paluxy Formation (HM, 1989).

2.2.1.4 Paluxy Formation

The Paluxy Formation consists of several thick sandstone layers separated by thin, discontinuous shale and claystone layers. In the upper part, differences in the individual sand and clay units can be subtle, and lateral facies changes are prevalent with minor amounts of clay, sandy clay, pyrite, lignite, and shale. The lower part of the unit is generally coarser grained than the upper part. The sandstone in this formation is porous, fine- to very fine-grained and comprised of moderately to well sorted, subangular to subrounded, mainly white quartz sand. Traces of pyrite, iron oxide, and glauconite occur in the sandstone. The finer-grained portion of the formation is comprised of gray to green-gray or olive green shales and silty claystones. Bedding in the gray to green-gray or olive green shales and silty claystones may be horizontally laminated, massive, or burrowed. These mudstones commonly contain thin beds of lignite.

The Paluxy Formation dips eastward at a shallow angle [0.4 degrees (°)] across the area. The Paluxy is exposed at the surface to the west of the study area, along the Lake Worth shoreline, and Meandering Road Creek (Figure 2-4). The overall thickness of the Paluxy Formation ranges from approximately 133 to 175 ft. The thickness of the individual sandstone and shaley units of the Paluxy varies across the area. HM (1989) divided the Paluxy into upper, middle, and lower units. This division was based on three distinct, continuous sandstone units separated by continuous beds of shale, claystone, and siltstone. In addition, a distinct sand unit, termed the Upper Sand, is present in the uppermost portion of the formation. Deep boreholes and geophysical logging have revealed only one unit of this formation (a shale/silty shale bed) that can be extensively mapped across the site.

Chem-Nuclear Geotech (1992) has challenged this division, based on evidence contained in core samples and geophysical logs. Chem-Nuclear Geotech suggests that only one unit, a single 3- to 5-ft-thick layer of silty shale to shale, is continuous within the Paluxy Formation. This unit is situated below an approxi-



PALUXY FORMATION OUTCROP
AIR FORCE PLANT 4 / CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 2-4

Source : ESE, 1994

Project No. : 3932033G-0310	
Date : February 1994	
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mately 5-ft thick layer of sandstone situated at the top of the formation. Frequent facies changes from coarser to finer-grained sequences are also noted.

2.3 STRUCTURE

The sedimentary rocks in the region were deposited within a stable setting on the Texas craton. The major structural features in the area include the Mexia-Talco fault system, which is located approximately 100 miles east of the study area, the Quachita overthrust about 30 miles east, and the south end of the axis of the Fort Worth basin, which is located directly under the site. The Fort Worth basin is a structural basin in which sediments accumulated during most of the Paleozoic era. No faults are known to exist within the upper subsurface (including the Goodland Limestone, Walnut Formation, or the Paluxy Formation) beneath the study area. Figure 2-5 portrays the location of the major structural elements in the region. The structural and depositional evolution of the area was highlighted by a period of uplift during the latter part of the Paleozoic era, during the Permian period. Throughout the Jurassic period, extensive erosion produced a flat surface on which Early Cretaceous period sediments were deposited. These rocks were deposited along the oscillating western shoreline of a major inland sea (East Texas Embayment). From the Late Cretaceous period through the Tertiary period, the sea withdrew toward the gulf, and, except for minor periods of subsidence, the land surface was eroded and modified by streams. During the Quaternary period, the streams deposited alluvial sediments. The older sediments are represented by terrace deposits above the alluvial-filled valleys of present streams.

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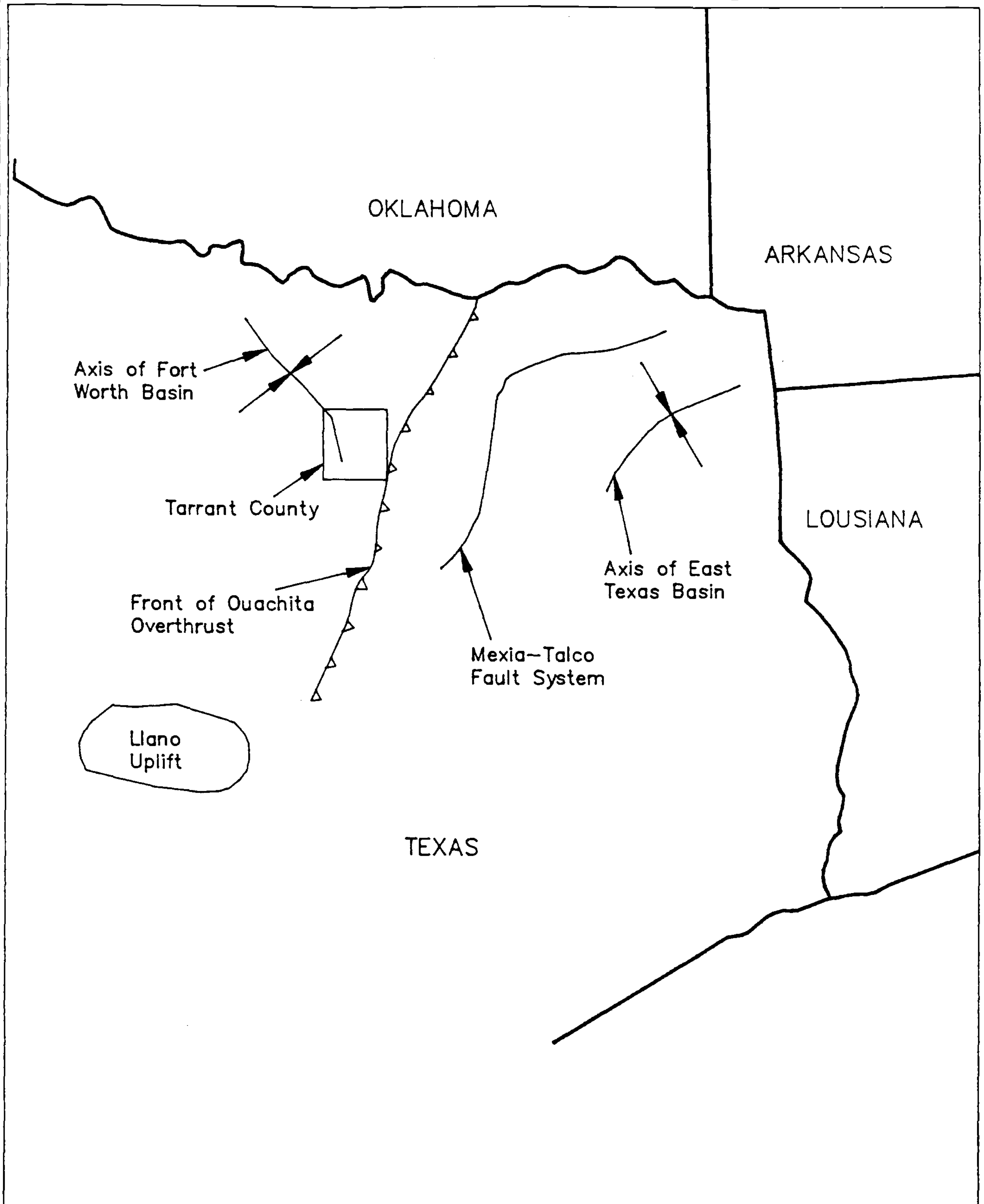

Source : FIGURE 2-6 GEOTECH, 1992

MAJOR STRUCTURAL FEATURES IN EAST TEXAS
AIR FORCE PLANT 4 / CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 2-5

Source : ESE, 1994

Project No. : 3932033G-0310
Date : February 1994
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3.0 HYDROGEOLOGY

3.1 REGIONAL HYDROGEOLOGY

The principal hydrogeological units in the region are as follows (listed in descending order):

1. Upper perched-water zones and water table zones within the alluvial terrace deposits (referred to herein as the Terrace Deposits),
2. Aquitard of predominantly dry limestone that comprises the Goodland and Walnut formations,
3. Aquifer within the consolidated clastics of the Paluxy Formation (called the Paluxy aquifer)
4. Aquitard of relatively impermeable limestone in the Glen Rose Formation, and
5. Aquifer within the sandstone of the Twin Mountains Formation.

The Paluxy and the Twin Mountains are the primary drinking water supply aquifers in the local area, but some groundwater from the Terrace Deposits is also used for residential and commercial uses. Because the Paluxy yields large amounts of high-quality groundwater and is closer to the surface than the Twin Mountains Aquifer, it has historically been the primary regional aquifer. The other major stratigraphic units in the area are of little importance to the hydrogeologic framework due either to their limited groundwater storage capacity or to the poor groundwater quality. Table 3-1 contains a summary of hydrogeological characteristics of the major stratigraphic units in the area.

3.2 SITE-SPECIFIC HYDROGEOLOGY

3.2.1 TERRACE DEPOSITS AQUIFER

The Terrace Deposits aquifer is an unconfined water table aquifer bounded vertically by the surface of the water table and the contact between Quaternary alluvial/terrace deposits/weathered bedrock and the underlying competent bedrock. The groundwater is stored within the pore space between the

Table 3-1. Hydrogeological Characteristics of the Regional Stratigraphic Units

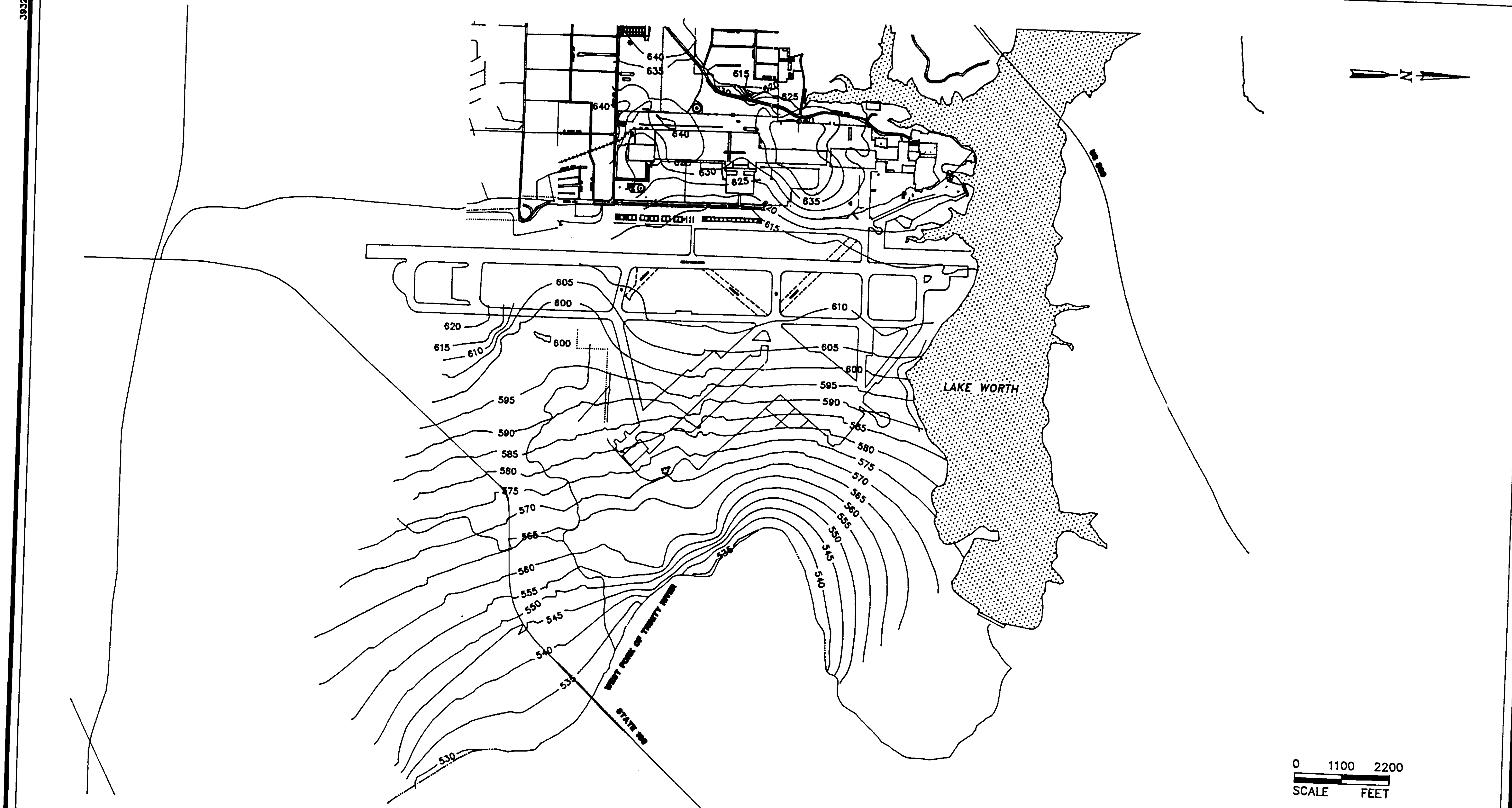
Series	Group	Stratigraphic Unit	Thickness (ft)	Water-Bearing Properties
Recent and Pleistocene		Alluvium	0-45	Small to moderate yields. Unsatisfactory as a potable source unless treated.
Gulf		Woodbine Formation Louisville Member	0-200+	Not known to yield water in the area.
		Dexter Member	0-110	Less mineralized than Louisville Member. Potable source in eastern Tarrant County.
Comanche	Washita	Grayson Shale	0-85	Not known to yield water in the Tarrant County area.
		Main Street Limestone	0-45	Not known to yield water in the Tarrant County area.
		Pawpaw Formation	0-40	Not known to yield water in the Tarrant County area.
		Weno Clay	0-75	Not known to yield water in the Tarrant County area.
		Denton Clay	0-35	Not known to yield water in the Tarrant County area.
		Fort Worth Limestone	0-35	Not known to yield water in the Tarrant County area.
		Duck Creek Formation	0-90	Not known to yield water in the Tarrant County area.
Comanche	Fredericksburg	Kiamichi Formation	0-40	Not known to yield water in the Tarrant County area.
		Goodland Limestone	0-130	Not known to yield water in the Tarrant County area.
		Walnut Formation	0-28	Not known to yield water in the Tarrant County area.
Comanche	Trinity	Paluxy Sand	140-190	Major source for potable and industrial uses in the area.
		Glen Rose Limestone	250-450	Potable source in some parts of western Tarrant County.
		Twin Mountains Formation	250-450	Principal aquifer in the area. Upper portion highly mineralized east of Fort Worth.
Paleozoic		Undifferentiated	6,000-7,000	Not tested. Not thought to contain fresh water.

Source: Radian Corporation, 1986.

individual grains of coarse sand and gravel of the alluvium and terrace deposits and, on a limited basis, within the cracks and crevices along the weathered surface of the underlying Goodland Formation. The storage capacity of the Terrace Deposits deposits are minimal due to the limited areal and vertical extent of the unit as a whole and because the coarser-grained bodies that store the groundwater are isolated into narrow, discontinuous lenses.

Recharge to the Terrace Deposits occurs through infiltration from precipitation and by hydraulic exchange with surface water bodies. Locally, some infiltration also occurs through leakage from water supply lines, firefighting pipe systems, cooling systems, and sanitary and storm sewers found throughout the facilities at CAFB and AFP4. The estimated volume of leakage from sewer and pipelines in the vicinity of the Assembly Building at AFP4 is approximately 316,000 gallons per day (gpd) (Chem-Nuclear Geotech, 1992). This substantial rate of infiltration causes a mounding of the potentiometric surface. Mounding also occurs in response to undulations in the surface of the underlying competent bedrock. These mounds increase the hydraulic head and an elevated hydraulic gradient, which, in turn, results in localized radial flow and increased flow rates of the groundwater in the Terrace Deposits. The increase in the flow rate can potentially decrease the dilution ratios of some contaminants. Discharge from the Terrace Deposits occurs primarily as seeps along Meandering Road Creek, base flows to Farmers Branch, discharge to the Trinity River, and through downward leakage into the Paluxy aquifer. The specifics of the groundwater flow characteristics are described in the following sections.

Water-level elevation measurements collected from the study area were used to construct the potentiometric surface map portrayed in Figure 3-1. The configuration of the potentiometric surface shown in this figure (September 1991) is consistent with that portrayed throughout the investigative history of the area. The dominant flow direction of the Terrace Deposits groundwater in



Note: Based on OCTOBER 1991 Data.

Figure 3-1
UPPER AQUIFER POTENTIOMETRIC SURFACE MAP

Source: ESE; CN GEOTECH.

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the study area, as depicted by the potentiometric map, is primarily eastward, although radial groundwater flow occurs in those areas where groundwater mounding occurs.

To calculate the average linear velocity of groundwater flow in the Terrace Deposits aquifer, the hydraulic conductivity values were determined using slug tests. The velocity was determined from the following equation (Bouwer and Rice, 1976):

$$V = Ki,^{n_e} \qquad \text{3-1}$$

Where: V = average linear velocity in the X direction (horizontal) [feet per day (ft/day)],

K = hydraulic conductivity (ft/day),

i = dh/dl, hydraulic gradient [feet per foot (ft/ft)], and

n_e = effective porosity (unitless).

The average hydraulic conductivity values ranged from 23.79 ft/day for the wells on the AFP4 property, to 8.13 ft/day for the Flightline Area at CAFB, to 6.98 ft/day for the East Area wells. For a conservative approximation, the average hydraulic conductivities were calculated by mathematical mean. Existing potentiometric maps were used to calculate an average hydraulic gradient of 0.005 for the Terrace Deposits aquifer across the site. To determine the average linear velocity of groundwater flow, an effective porosity value of 0.30 (Fetter, 1980) was used. This value was selected because the size of the individual grains that comprise the terrace and alluvial sediments varies from gravel to clay size, and 0.30 represents a mid-range value in the order of that expected for sand-size grains. The average groundwater flow rates at AFP4, the Flightline Area at CAFB, and the East Area at CAFB, are 0.39 ft/day, 0.14 ft/day, and 0.12 ft/day, respectively. Hydraulic conductivities and calculated flow rates for

AFP4, the Flightline Area at CAFB, and the East Area at CAFB, are presented in Tables 3-2, 3-3, and 3-4, respectively.

Given an estimated average thickness of the Terrace Deposits aquifer of 25 ft, as determined from existing boring logs, the measured conductivity values for each site were used to calculate transmissivity values of 595 square feet per day (ft^2/day) for AFP4, 208 ft^2/day for the Flightline Area, and 175 ft^2/day for the East Area. The transmissivity was calculated using the following equation:

$$T = Kb \qquad \text{3-2}$$

Where: T = transmissivity (ft^2/Day)
K = hydraulic conductivity (ft/Day)
b = aquifer thickness (ft)

The average groundwater flow rates calculated for the AFP4 property, Flightline Area, and East Area are relatively consistent between the sites, although wide variations do occur between the values measured at the individual sites. This variation is likely a function of the wide variation in grain size and the discontinuity of the individual sediment lenses that characterize the Terrace Deposits deposits. The gravel zones are highly porous and permeable and represent areas where groundwater within the Terrace Deposits flows at a significantly higher rate relative to the other areas within the aquifer. The paleochannels previously described likely represent zones of significantly elevated flow rates, because lithologic logs indicate that they are areas where the basal gravel accumulates into thick (upwards to 15 ft) deposits (HM, 1989).

3.2.2 GOODLAND/WALNUT AQUITARD

The finer-grained marl, shale, and clay portions of the Goodland Limestone and the Walnut Formation restrict the vertical movement of groundwater through the units. This circumstance creates an aquitard that restricts the vertical flow of

Table 3-2. AFP4 Terrace Deposits Groundwater Flow Rates

Monitor Well Number	Hydraulic Conductivity (ft/day)	Groundwater Flow Rate (ft/day)
W-128L	.03	5×10^{-4}
W-131U	28.62	0.48
W-133L	5.19	0.09
W-136	.18	3×10^{-3}
W-140	29.76	0.50
W-141U	.22	3.7×10^{-3}
W-143	85.02	1.42
W-144	320.23	5.34
W-147	1.14	0.02
W-149	.33	5.5×10^{-3}
W-151	.07	1.2×10^{-3}
W-153	10.08	0.17
W-156	.05	8.3×10^{-4}
W-157	.28	4.6×10^{-3}
W-158	9.01	0.15
W-159	44.49	0.74
W-160	15.93	0.27
F-208	.76	1.3×10^{-2}
F-212	.01	1.7×10^{-4}
F-216	5.84	0.09
F-217	6.57	.11
HM-12	.16	2.7×10^{-3}
HM-27	3.06	0.05
HM-28	19.55	0.33
HM-105	8.05	0.13
Average*	23.79	.39

Note: Flow rate based on a measured hydraulic gradient of 0.005 ft/ft and a porosity value of 0.3 (Fetter, 1980).

*Average was calculated using mathematical mean method.

Source: Chem-Nuclear Geotech, Inc., 1992.

Table 3-3. Terrace Deposits Groundwater Flow Rates, CAFB Flightline Area

Monitor Well Number	Hydraulic Conductivity (ft/day)	Groundwater Flow Rate (ft/day)
LF04-4A	1.2	.02
LF04-4D	22.6	.38
LF04-4E	17.9	.29
LF04-4G	11.3	.19
LF05-5A	6.2	.10
LF05-5C	5.4	.09
LF05-5D	5.1	.08
LF05-5E	6.2	.10
FT09-12A	1.7	.03
FT09-12B	4.2	.07
FT09-12C	7.7	.13
Average*	8.14	.13

Note: Flow rate based on a measured hydraulic gradient of 0.005 ft/ft and a porosity value of 0.3 (Fetter, 1980).

*Average was calculated using mathematical mean method.

Source: Radian Corporation, 1991.

Table 3-4. Terrace Deposits Groundwater Flow Rates, CAFB East Area

Monitor Well Number	Hydraulic Conductivity (ft/day)	Groundwater Flow Rate (ft/day)
LF01-1D	.03	1×10^{-3}
LF01-1F	3.91	.07
ST14-17J	1.71	.03
ST14-17K	1.54	.03
ST14-17L	34.00	.57
ST14-17M	.71	.01
Average*	6.99	.12

Note: Flow rate based on a measured hydraulic gradient of 0.005 ft/ft and a porosity value of 0.3 (Fetter, 1980).

*Average was calculated using mathematical mean method.

Source: Radian Corporation, 1991.

groundwater between the Terrace Deposits and Paluxy aquifers. The original thickness of the Goodland has been reduced over the entire area through weathering of its upper surface when the unit was exposed at the surface. Most of the Goodland, and the entire section of the Walnut, are thought to be continuous throughout most of the subsurface beneath the study area, except in those areas that have been affected by erosional paleochannel development. In those areas where the channel development was extensive, the Goodland and Walnut rocks are nearly or completely eroded away, thus leaving the Terrace Deposits deposits in contact with the Paluxy Formation. One area of paleochannel development, identified in previous investigations is commonly referred to as the Window Area and is located beneath the East Parking Lot at AFP4. Window refers to the fact that, because erosion of the Goodland/Walnut is so severe, its ability to retard the vertical movement of groundwater has been significantly reduced, thus allowing for the uninhibited exchange of groundwater (and any contaminants) between the Terrace Deposits and Paluxy aquifers.

The Window Area has been targeted for thorough investigations to determine the degree of exchange occurring between the two aquifers. Well clusters have been installed in the Window Area to address this concern. The clusters are typically comprised of two monitor wells: one completed in the Terrace Deposits and the other completed into the upper sands of the Paluxy aquifer. These clusters are constructed in such a manner to measure and compare the changes in water level that may occur over time within the two aquifers and to measure the vertical hydraulic conductivity through the Goodland/Walnut aquitard. Paired wells in the Window Area include P-14US/HM-86, P-15US/HM-90, and P-16US/HM-94. Those wells with the "P" designation are completed within the Paluxy aquifer; those with the "HM" designation are Terrace Deposits wells.

Because vertical flow from the Terrace Deposits into the Paluxy Formation is a case of flow perpendicular to layering, the expression for the equivalent vertical hydraulic conductivity is as follows (Bouwer and Rice, 1976):

$$\begin{array}{ll} \sum K_z & = d \\ \lim & \overline{d_i} \\ n \rightarrow i & \overline{K_i} \end{array} \qquad 3\text{-}3$$

Where: K_z = equivalent vertical hydraulic conductivity,
d = combined thickness of heterogeneous units,
d_i = individual thickness of strata i,
K_i = hydraulic conductivity of strata i.

The equivalent vertical hydraulic conductivities for the three Window Area well pairs are presented in Table 3-5. These values were used to estimate the vertical Darcy flux and average linear vertical velocity of groundwater through the Walnut Formation in the Window Area, which are presented in Table 3-6.

The measured K_i values are not available for the Walnut Formation in the Window Area because the Walnut rocks are very thin (if not completely absent) in this area. The K_i value was assumed to be two orders of magnitude greater than the logarithmic mean K value measured in those areas where the Walnut rocks are complete. The K_i value for the Paluxy was set equal to 5.7 x 10^{-5} ft/day, which is the logarithmic mean of the vertical hydraulic conductivities measured for core samples collected from the Paluxy. The porosity value of 0.074 percent, used to calculate the average linear velocity throughout the Walnut Formation, was also determined from the logarithmic mean as measured in core samples.

The estimated vertical flow velocity through the Walnut Formation suggests that downward leakage is minimal at any location where the integrity of the Goodland/Walnut aquitard remains intact. Thus, the groundwater of the Terrace Deposits and Paluxy aquifers is in direct exchange only at those areas where the Goodland/Walnut stratum has been significantly eroded.

Table 3-5. Equivalent Vertical Hydraulic Conductivity Values Through the Walnut Formation

Sample Location	K_i Walnut (ft/day)	d_i Walnut (ft)	K_i Paluxy (ft/day)	d_i Paluxy (ft)	d (ft)	K_z (ft/day)
HM-86 and P-14US	1.9×10^{-4}	6.6	5.7×10^{-5}	4.75	26	2.2×10^{-4}
HM-94 and P-15US	1.9×10^{-4}	2.0	5.7×10^{-5}	2.5	18.0	3.3×10^{-4}
HM-90 and P-16US	1.9×10^{-4}	2.25	5.7×10^{-5}	3.5	19.35	2.7×10^{-4}

Source: Chem-Nuclear Geotech, 1992.

Table 3-6. Average Vertical Linear Velocity Through the Walnut Formation

Sample Location	K_i (ft/day)	Porosity*	Hydraulic Gradient*	Vertical Average Linear Velocity (ft/day)
HM-86 and P-14US	2.2 x 10^{-4}	0.074	1.1	3.23 x 10^{-4}
HM-94 and P-15US	3.3 x 10^{-4}	0.074	1.2	5.22 x 10^{-3}
HM-90 and P-16US	2.7 x 10^{-4}	0.074	0.3	1.16 x 10^{-3}

* Unitless.

Source: Chem-Nuclear Geotech, 1992.

3.2.3 PALUXY AQUIFER

Lithologic evidence collected during previous investigations indicates that the Paluxy aquifer is a single, unconfined to partially confined flow system. The groundwater is contained within the openings created by gaps between bedding planes, cracks, and fissures of a sandstone matrix. The sandstone is interbedded with abundant layers of discontinuous, interbedded shale, siltstone, and claystone, which restrict the vertical movement of groundwater within the aquifer over limited areas. The overall thickness of the Paluxy Formation ranges from 140 to 190 ft across the study area. The thickness of the saturated portion of the formation is relatively uniform across the region. Under static conditions, groundwater within the Paluxy is normally confined where the overlying Goodland/Walnut aquitard is present. However, extensive pumping has occurred with the development of the Fort Worth area, thus lowering the Paluxy potentiometric surface to a point located below the top of the formation over most of the area.

Development of the Paluxy aquifer began in the early 1900s. Production in the Tarrant County area peaked in the 1960s but has been in a state of decline since that time due to large drops in the hydraulic head caused by over-production. Seven wells in White Settlement pump water from the Paluxy for municipal use. The average daily production from each of these wells is just over 69,099 gallons. Table 3-7 presents a profile of these wells.

Recharge to the Paluxy aquifer occurs where the Paluxy Formation outcrops west of the Fort Worth area and from Lake Worth. Because the rocks of the Paluxy Formation dip eastward at a shallow angle, the groundwater within the Paluxy aquifer flows eastward in the direction of the regional dip (Figure 3-2). The gradient ranges from 20 ft/5,200 ft (0.004) to 20 ft/1,700 ft (0.012) across the study area (for an average of 0.008). The groundwater flow direction is locally affected by recharge from Lake Worth and by drawdown, caused by pumping

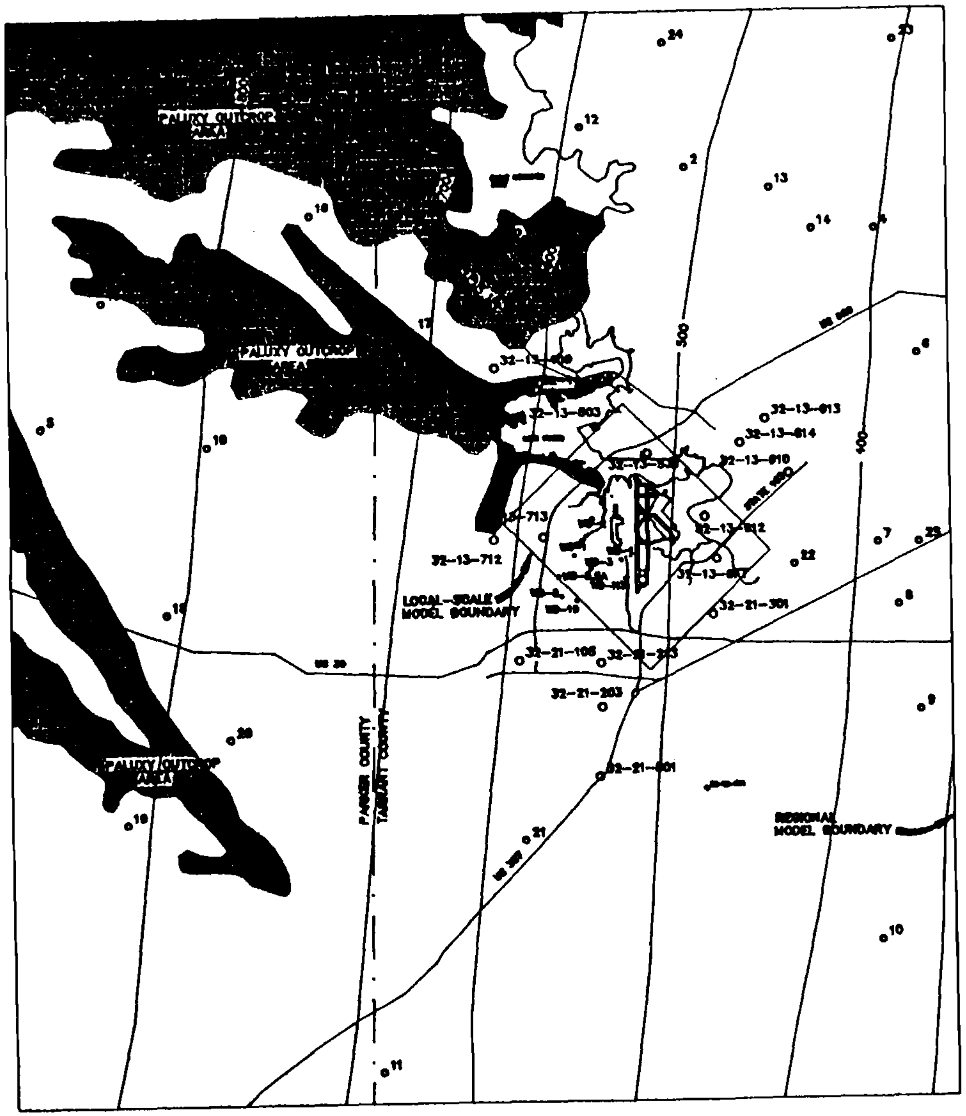
Table 3-7. Profile of White Settlement Production Wells

Monitor Well Number	Total Depth (ft)	Depth of Screened Interval (ft-bls)	Average Daily Production (gal/day)
WS-1	254	Not Available	55,519
WS-2	200	Not Available	55,535
WS-3	201	180-200	63,332
WS-H3	282	212-242	56,500
WS-5A	305	175-305	63,593
WS-8	286	175-286	99,541
WS-12	195	Not Available	89,670

Source: ESE (From City of White Settlement).

PLOTTED: Apr 16, 1991 - 11:26:14

F:\..\OTISMAN\3932033G\FIG3-2.DWG



0 7500 15000
SCALE FEET

LEGEND

WS-3	WHITE SETTLEMENT PRODUCTION WELLS
32-13-614	PRODUCTION WELL IDENTIFIED IN STATE WELL RECORDS
1	PRODUCTION WELL LOCATION OBTAINED FROM NORDSTROM (1982).

NOTE: ELEVATIONS ARE IN FEET MSL
SOURCE: NORDSTROM, 1982.

PALUXY AQUIFER POTENTIOMETRIC SURFACE MAP
AIR FORCE PLANT 4/CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 3-2

Source : ESE, 1994

Project No. : 3932033G-0310
Date : February 1994
Drawn By : N.M.D.
Checked By : M.A.B.
Approved By : M.J.G.

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from the potable wells in the community of White Settlement. This circumstance causes a more southeasterly groundwater flow in the runway area and a southwesterly flow direction in the Meandering Creek Road area.

To determine the horizontal hydraulic conductivity of the Paluxy aquifer, slug tests were conducted on the four monitor wells installed during the 1991 RI (Chem-Nuclear Geotech, 1992). The results of the tests are provided in Table 3-8. The wells with a "U" designation are completed within the upper part of the aquifer, and those with an "M" designation are completed within the middle part. These measurements were used to calculate the groundwater flow rates within the aquifer. The conductivity values ranged from 1.88 to 10.88 ft/day and averaged 6.42 ft/day. Using the measured average hydraulic gradient of 0.008 and an average measured effective porosity of 0.27, the average linear velocity in the Paluxy is likely within the range of 0.06 to 0.32 ft/day and averages 0.19 ft/day. The vertical hydraulic conductivity rates vary between sample locations, probably reflecting the complexity of the interbedding of lithologic units within the formation.

Additional flow rates and transmissivity values were also calculated based on the results of pump tests conducted during a 1985 investigation (HM, 1985). These results are presented in Table 3-9. The conductivity values ranged from 15.2 to 76.9 ft/day and averaged 35.9 ft/day. These readings translated into flow rates that ranged from 0.40 ft/day to 2.28 ft/day, for an average of 1.06 ft/day. The drawdown values averaged 2,224 ft/day, and the recovery values averaged 1,661 ft/day. The reported transmissivity rates in the Paluxy aquifer range from 1,263 to 13,808 gallons per day per foot (gpd/ft) and averaged 3,700 gpd/ft across the area (CH2M-Hill, 1984).

3.2.4 GLEN ROSE AQUITARD

The Glen Rose Formation is comprised of an approximately 450-ft thick section of fine-grained limestone, shale, marl, and sandstone of the Glen Rose

Table 3-8. Paluxy Aquifer Groundwater Flow Rates*

Monitor Well Number	Horizontal Hydraulic Conductivity (ft/day)	Horizontal Flow Rate (ft/day)
P-27U	10.88	.32
P-28U	1.88	.06
P-29M	5.18	.15
P-30M	7.74	.23
Average†	6.42	.19

Note: Flow rate based on a measured average hydraulic gradient of 0.008 ft/ft and a porosity value of 0.27 (Advanced Terra Testing, 1991).

*As determined by slug tests.
†Average was calculated using mathematical mean method.

Source: Chem-Nuclear Geotech, 1992.

Table 3-9. Paluxy Aquifer Groundwater Flow Rates and Transmissivity Values*

Monitor Well Number	Transmissivity Drawdown (ft/day)	Transmissivity Recovery (ft/day)	Hydraulic Conductivity (ft/day)	Flow Rate (ft/day)
P-1	4011	3209	60.2	1.74
P-2	1872	2273	51.8	1.53
P-3	NA	1110	15.8	.47
P-4	1016	749	17.6	.52
P-5M	2139	1110	40.6	1.20
P-6M	3209	989	42.0	1.24
P-7M	NA	535	13.4	.40
P-8M	4278	4947	76.9	2.28
P-9M	936	1110	25.6	.76
P-10M	334	575	15.2	.45
Average†	2224	1661	35.9	1.06

Note: Flow rate based upon an estimated average hydraulic gradient of 0.008 ft/ft and a measured porosity value of 0.27 (Advanced Terra Testing, 1991).

*As determined by pump tests.
†Average was calculated using mathematical mean method.

Source: Chem-Nuclear Geotech, 1992 (Modified from H&M, 1985).

Formation. Although the Glen Rose Formation sands yield small quantities of groundwater in the area, the limited porosity and permeability of the finer-grained portions of the unit restrict the vertical flow of groundwater. This creates an aquitard that restricts the flow of groundwater between the Paluxy and Twin Mountains aquifers.

3.2.5 TWIN MOUNTAINS AQUIFER

The Twin Mountains Formation is the deepest source of groundwater within the study area. The Twin Mountains Formation consists of a basal conglomerate of chert and quartz and grades upward into a coarse to fine-grained sandstone interbedded with shale. The thickness of the formation varies between 250 and 430 ft across the area. Recharge to the Twin Mountains aquifer occurs west of Fort Worth, where the formation crops out at the surface. As with the Paluxy, the regional direction of groundwater movement within the Twin Mountains is eastward in the downdip direction. Also, as with groundwater within the Paluxy, groundwater within the Twin Mountains occurs under water-table conditions in its recharge areas and becomes confined as the water moves downdip.

The Twin Mountains aquifer is the principal aquifer in the Tarrant County area. The formation yields large water supplies for municipal and industrial purposes. Groundwater withdrawals from the Twin Mountains aquifer, primarily for municipal water supply, have resulted in declining water levels. Between 1955 and 1976, the potentiometric surface of the aquifer dropped approximately 250 ft. Water quality in the Twin Mountains aquifer is suitable for potable use throughout the Fort Worth area. Groundwater in the upper sands portion of the aquifer is considered too mineralized for human consumption.

The reported transmissivity rates in the Twin Mountains aquifer range from 1,950 to 29,700 gpd/ft and average 8,450 gpd/ft in Tarrant County (CH2M-Hill, 1984). Permeability rates range from 8 to 165 gpd/ft^2 and average 68 gpd/ft^2 in the area.

4.0 CONTAMINANT FATE AND TRANSPORT

The information presented in the following section contains a historical review of groundwater contamination, transport and fate of groundwater contamination independent of remedial action, and a description of the simple mathematical techniques used for plume transport approximations. Specifically, TCE is the primary contaminant addressed in this section; however, 1,2-DCE and vinyl chloride are included to a lesser extent. The information presented in this section will be used for completing the FS for this study area.

4.1 HISTORY OF TCE MIGRATION

4.1.1 HISTORY OF DISSOLVED TCE MIGRATION

TCE and TCE degradation products were detected in the groundwater beneath AFP4 in 1983. The groundwater contamination was detected during the Phase I, Investigation of Subsurface Conditions at AFP4, conducted by HM (1983). HM installed and sampled a series of Terrace Deposits and Paluxy monitor wells to determine the extent and source(s) of groundwater contamination. The extent of TCE contamination in the Terrace Deposits, as determined by groundwater samples collected in May and June 1983, is depicted in Figure 4-1. Phase I activities focused on the west/south side of AFP4. Groundwater samples indicated that a high concentration of TCE was present throughout the study area. Additional subsurface investigations were required to define the horizontal and vertical extent of contamination in the Terrace Deposits and Paluxy aquifers.

In 1984, IRP Phase I studies were completed at AFP4 and CAFB. The records search conducted by CH2M Hill identified 40 disposal sites on CAFB and AFP4. The IRP Phase II, Stage I, confirmation/quantification investigations provided additional information concerning the presence of TCE contamination in the groundwater beneath AFP4 and CAFB. As a result of the IRP Phase II investigations, a larger groundwater monitoring network was installed. The groundwater monitoring network, which consisted of Terrace Deposits and

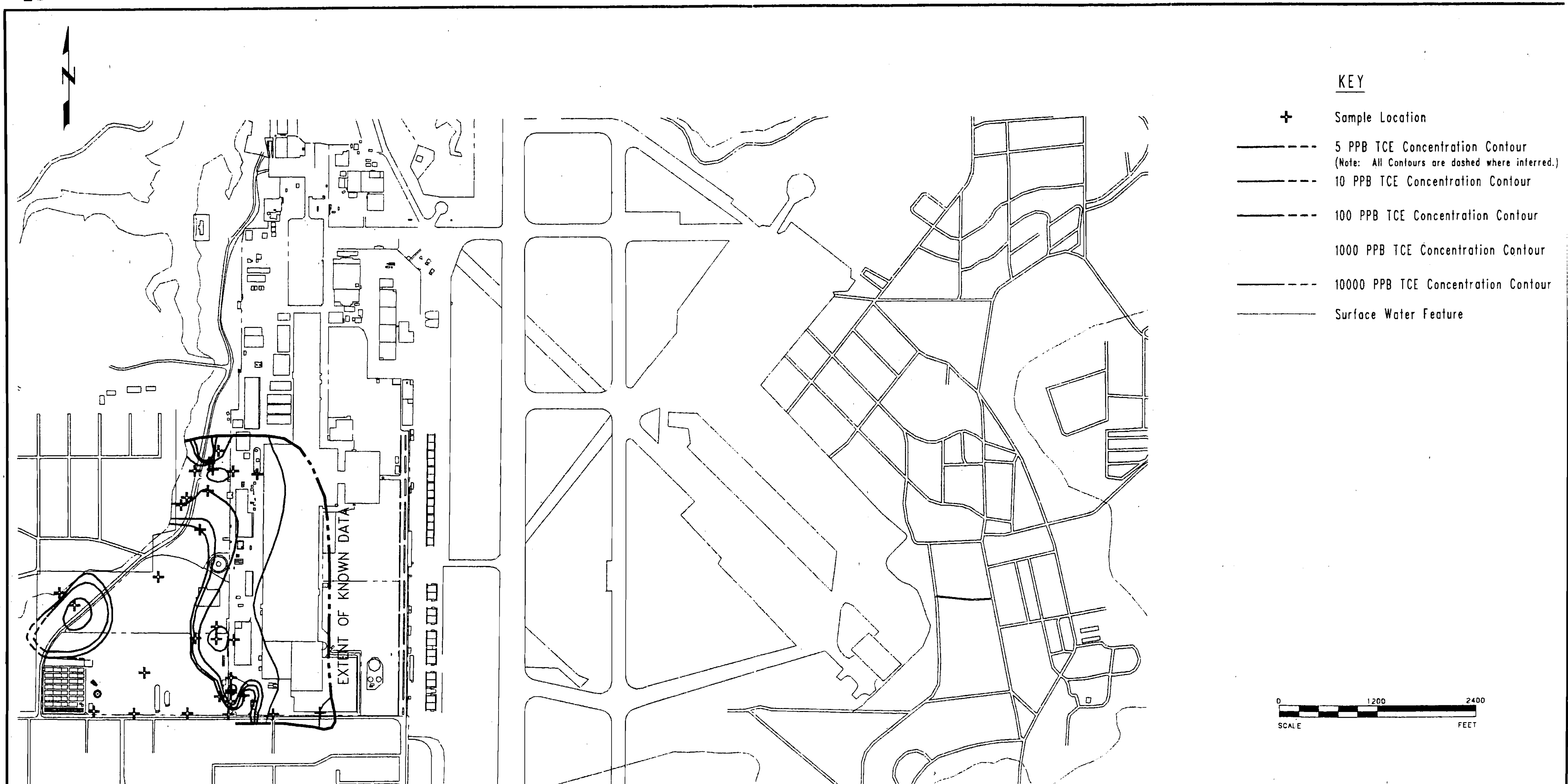

Figure 4-1	Terrace Deposits, Trichloroethene Concentrations - Summer, 1983

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1983

Paluxy monitor wells, was installed within the disposal sites documented in the Phase I studies. Despite the additional monitor wells, the extent of the groundwater contamination was not determined. Additionally, groundwater samples collected from the Paluxy monitor wells indicated that the Paluxy aquifer was impacted in the vicinity of the Window Area. To determine groundwater quality in the Terrace Deposits and Paluxy aquifer over a sustained time period, groundwater monitoring plans were implemented on a quarterly basis. The extent of TCE in the Terrace Deposits, as determined by data collected during October 1986, is depicted in Figure 4-2.

Additional subsurface investigations, primarily at AFP4, were conducted to define groundwater quality in specific areas. Interim remedial investigations focussing on the East Parking Lot area resulted in the installation of additional Paluxy and Terrace Deposits monitor wells. The extent of TCE contamination in the Terrace Deposits, as determined by data collected in October 1989, is depicted in Figure 4-3. The extent of TCE contamination in the Paluxy aquifer is depicted in Figure 4-4. The majority of the contamination in the Terrace Deposits is moving to the east, with the bulk movement of water (advection). TCE was detected in the Paluxy aquifer beneath the East Parking Lot and beneath LF03 in Paluxy well P-22U and P-22M. The TCE detected in the Paluxy aquifer is moving to the southeast, under the influence of the White Settlement production wells.

The results of the RI (Chem-Nuclear Geotech, 1992) completed at AFP4 and the Flightline Area indicated the shape of the TCE plume did not alter from 1989 to 1991. The TCE plume in the Terrace Deposits can be separated into three smaller plumes (West Plume, North Plume, and East Parking Lot Plume). The Terrace Deposits groundwater plumes are depicted in Figure 4-5, based on data collected in 1991. The groundwater mounding present below Building 12 has resulted in a radial flow that is moving TCE contamination in three separate directions. In general, the hydraulic gradient calculated in the North and West plumes is small, reducing the groundwater flow velocity and the transport of

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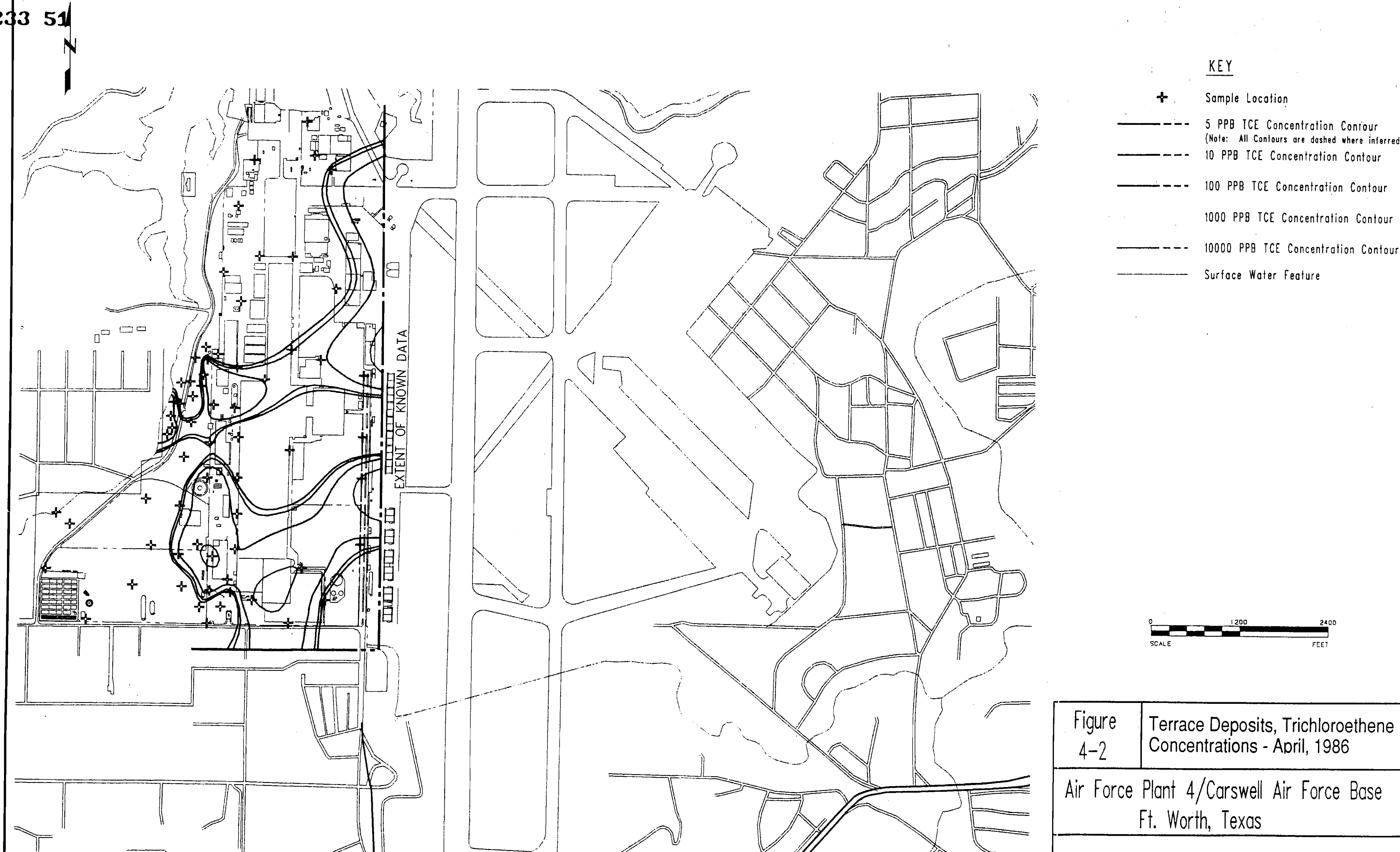


Figure 4-2

Terrace Deposits, Trichloroethene Concentrations - April, 1986

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1986

233 52

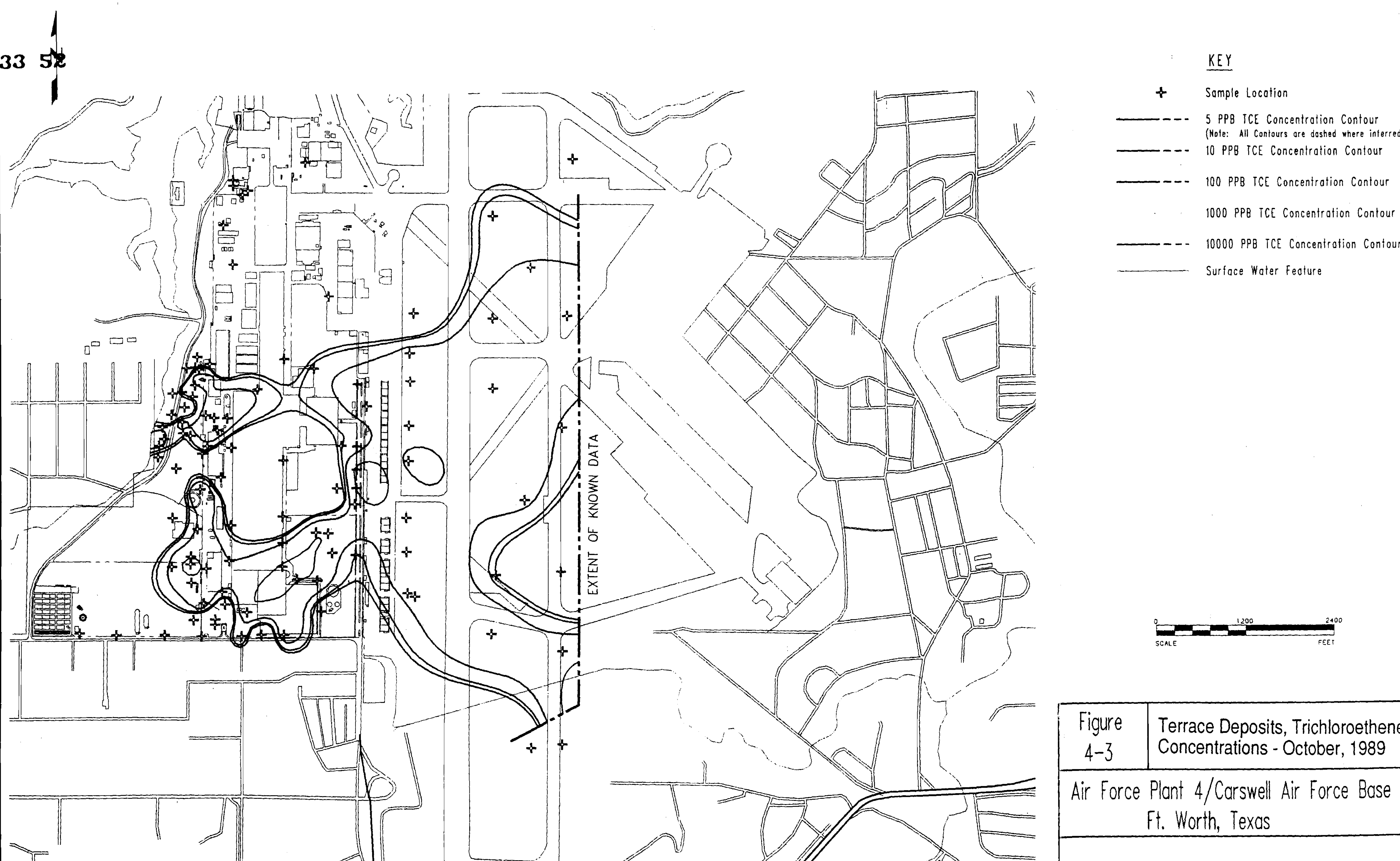


Figure 4-3

Terrace Deposits, Trichloroethene Concentrations - October, 1989

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1989

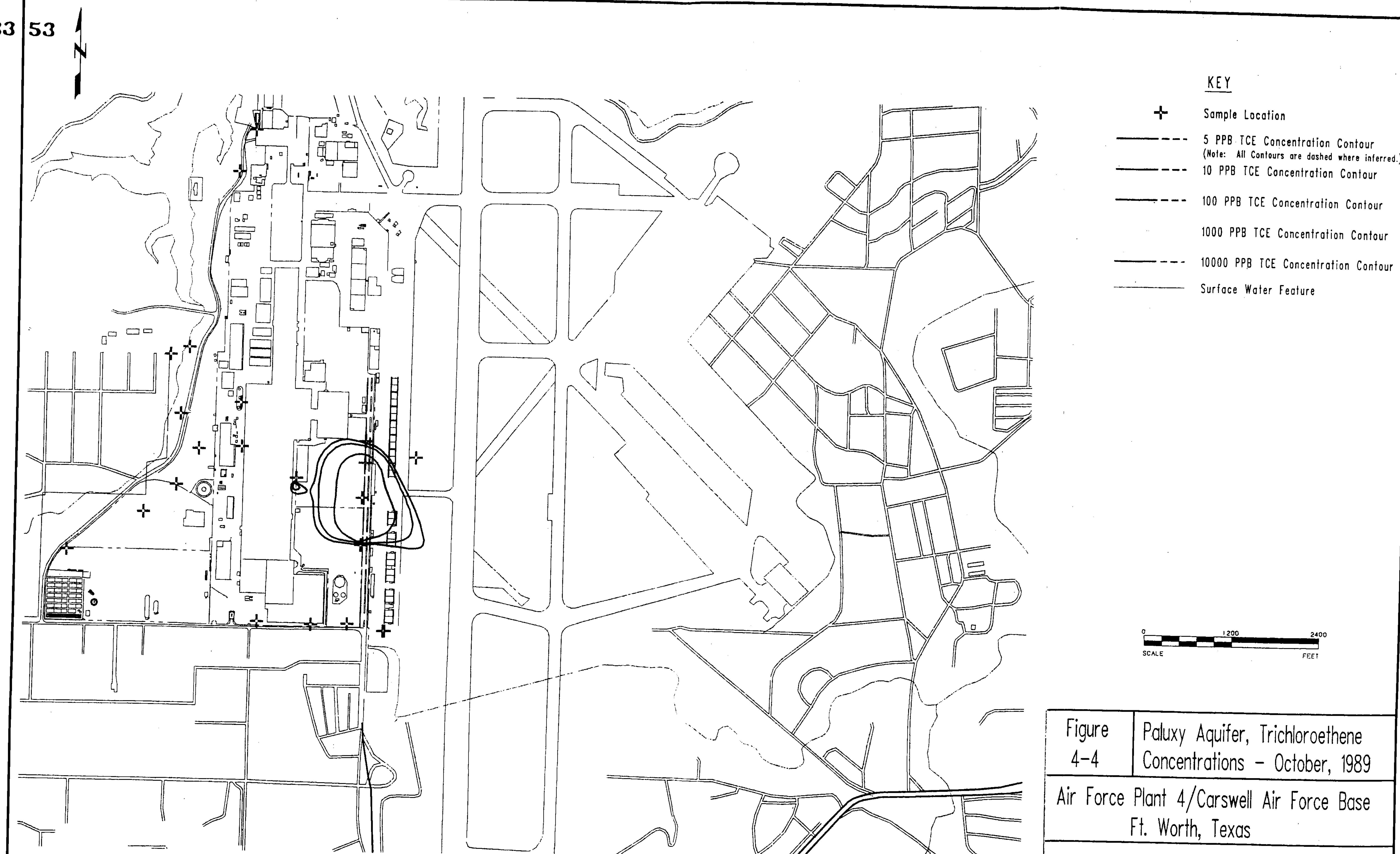
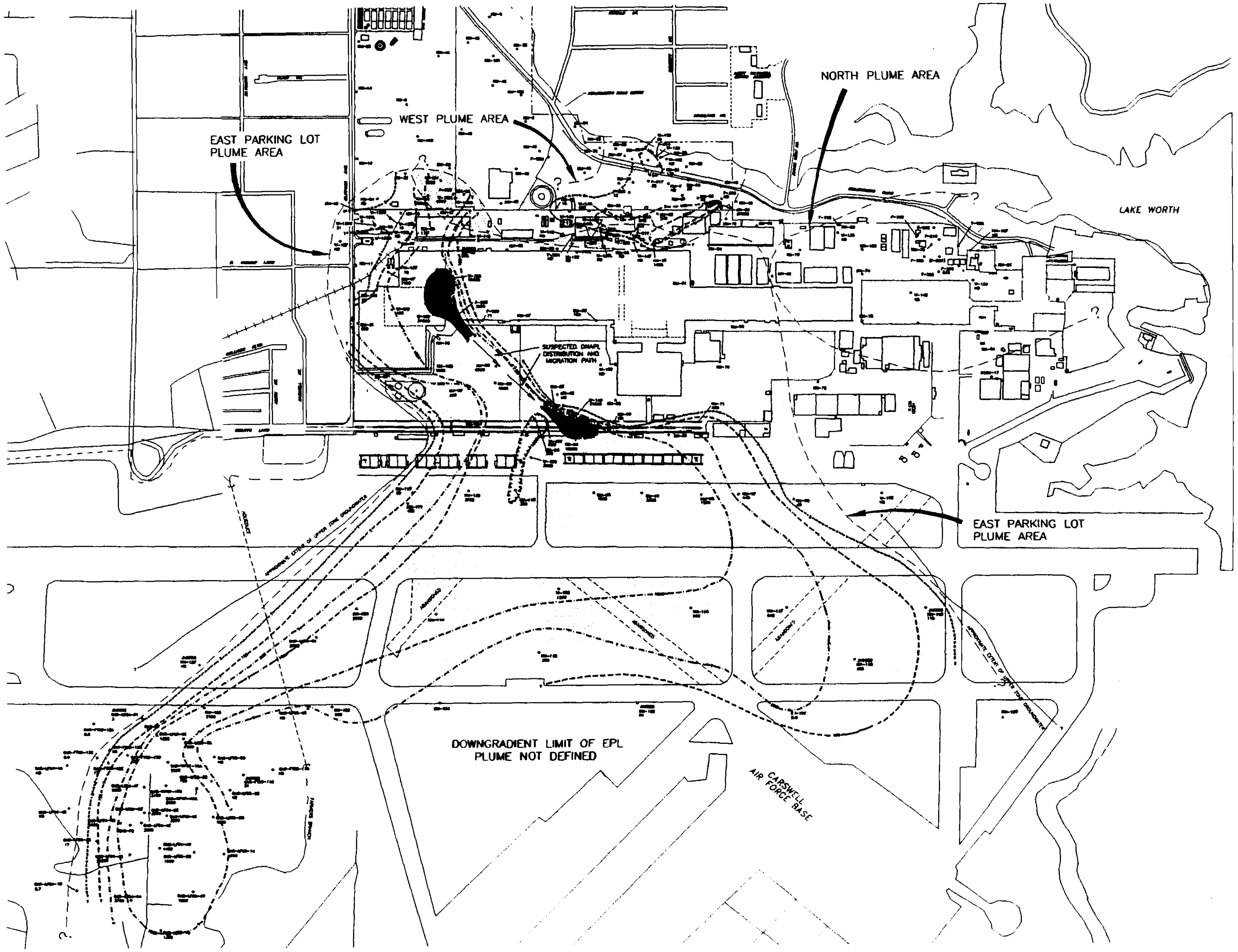


Figure 4-4	Paluxy Aquifer, Trichloroethene Concentrations - October, 1989
Air Force Plant 4/Carswell Air Force Base Ft. Worth, Texas	
U.S. Army Corps of Engineers	

Sources: ESE, 1994; CN Geotech, 1989



LEGEND

ORIGINAL WELL LOCATIONS

NEW MONITORING WELL LOCATIONS (GEOTECH)

CARSWELL AFB WELLS (LOCATIONS ARE APPROXIMATE)

CONCENTRATION OF TRICHLOROETHENE IN MICROGRAMS PER LITER

5 μg/L
100 μg/L
500 μg/L
1000 μg/L
10000 μg/L
CONTOURS OF EQUAL CONCENTRATIONS OF TRICHLOROETHENE IN MICROGRAMS PER LITER

QUALIFIERS FOR ORGANIC SAMPLES

ND BELOW INSTRUMENT DETECTION LIMIT
J INDICATES AN ESTIMATED VALUE
B INDICATES THE ANALYTE WAS FOUND IN THE ASSOCIATED LABORATORY BLANK

NOTES:

1. BASED ON 1991 SAMPLES OR MOST RECENT AVAILABLE DATA IN 1990 IF MORE THAN ONE SAMPLE WAS COLLECTED THE HIGHEST REPORTED VALUE AND/OR THE VALUE WITHOUT ANY QUALIFIER IS SHOWN.
2. ALL SAMPLES WERE COLLECTED BY GEOTECH, EXCEPT THOSE IDENTIFIED AS JACOBS, WHICH WERE COLLECTED BY JACOBS ENGINEERING IN 1991, AND SPRING 1992.
3. ALL SAMPLES REPORTED FROM CARSWELL AFB WELLS (CAR-) WERE COLLECTED BY RADIAN CORP. IN SPRING 1990, EXCEPT THOSE IDENTIFIED AS JACOBS, WHICH WERE COLLECTED BY JACOBS ENGINEERING IN THE SPRING OF 1992.

0 400 800 1600
SCALE IN FEET

SOURCE: CN GEOTECH, 1993.

TERRACE DEPOSITS TRICHLOROETHENE CONCENTRATIONS - 1991
AIR FORCE PLANT 4/CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 4-5

Project No.: 3932033G-0320-3120	US ARMY CORPS OF ENGINEERS
Date: March 1994	
Drawn By:	ESE Environmental Science & Engineering, Inc.
Checked By:	
Approved By:	

contaminants. The hydraulic gradients are influenced by the surface water bodies surrounding the study area. Specifically, Lake Worth and Meandering Road Creek influence the gradient of the North and West plumes. The TCE plume in the Paluxy aquifer, as determined by 1991 analytical data, is depicted in Figure 4-6.

The areal extent of TCE; 1,2-DCE; and vinyl chloride in the Terrace Deposits, as determined by analytical data collected in October 1993 by Jacobs (1993), and analytically presented by Geo-Marine (1993), is depicted in Figures 4-7, 4-8, and 4-9, respectively. The extent of TCE in the Terrace Deposits, West, and East Parking Lot plumes, as reflected by the latest data set, did not alter much from 1991 to 1993; however, TCE was not detected in the North plume area. The extent of TCE in the East Parking Lot has migrated downgradient of the known 1991 extent of TCE contamination. The extent of TCE contamination, according to the data presented in the Geo-Marine report (1993), was determined by using a hydropunch collection system and mobile laboratory; however, since the groundwater samples were not collected from a properly installed monitor well, the accuracy and precision of the study is questionable.

The areal extent of TCE; 1,2-DCE; and vinyl chloride in the Paluxy aquifer, as determined by groundwater data collected in October 1993, is shown in Figures 4-10, 4-11, and 4-12, respectively. The contaminant plume, located beneath the East Parking Lot, has increased in strength and size since 1989 (Figure 4-4). The small amount of contamination detected beneath LF01 and LF03 has decreased in strength. It is possible that the contamination detected in this area in 1991 has moved into the East Parking Lot Paluxy plume. The vertical extent of TCE in the Paluxy aquifer is shown in Figure 4-13. Based on the latest analytical data, the TCE contamination is located in the upper sand portion of the Paluxy aquifer; however, historical analytical data reflect minor contamination by TCE and TCE degradation products in the upper Paluxy zone.

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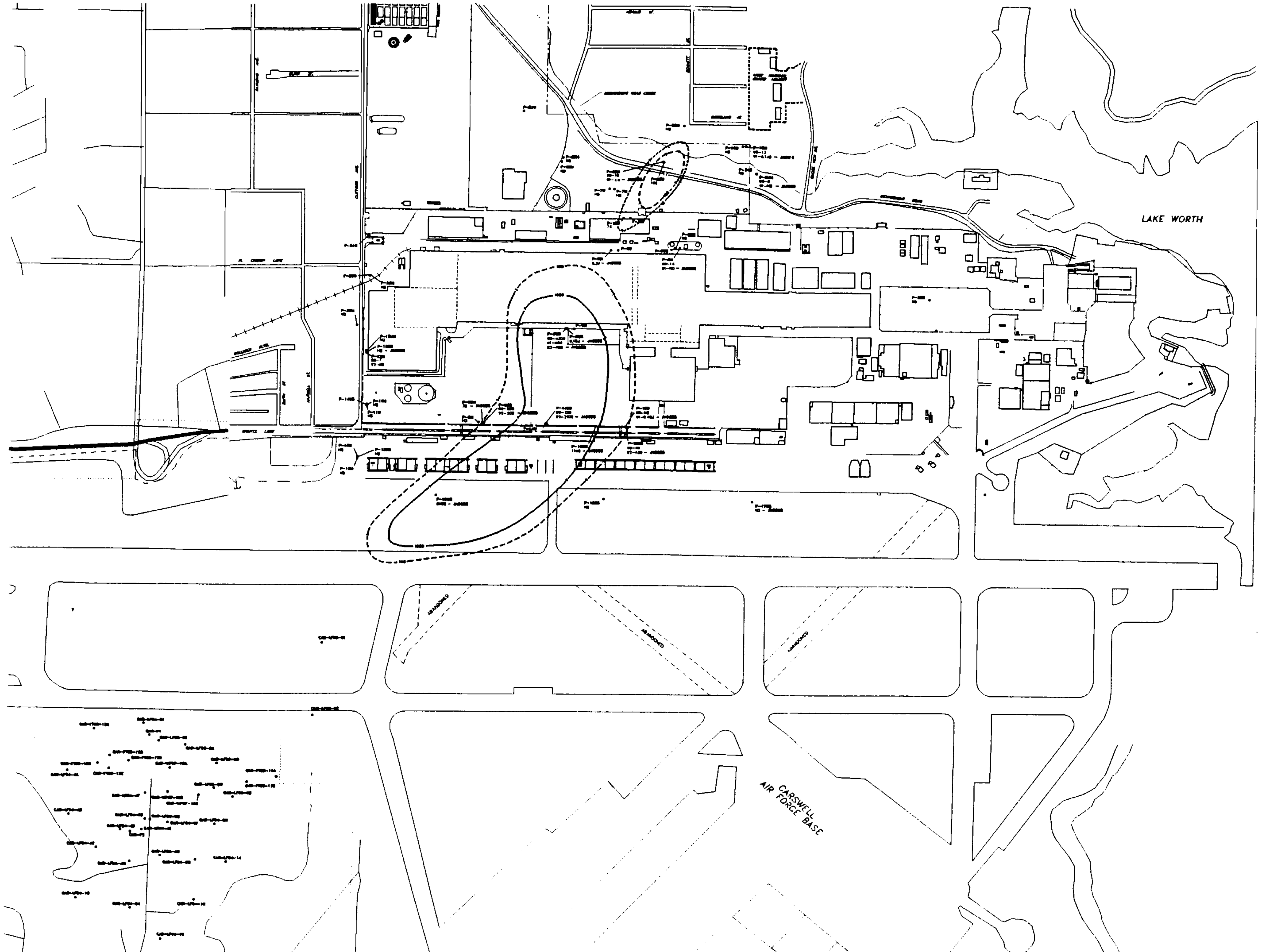


LEGEND

P-27U	PALUXY MONITORING WELL LOCATIONS
CAR-LF06-02	CARSWELL AFB WELLS (LOCATIONS ARE APPROXIMATE)
P-9US 91-75	YEAR SAMPLED (WHEN NOTED) AND CONCENTRATION OF TRICHLOROETHENE IN MICROGRAMS PER LITER; YEAR SAMPLE WAS COLLECTED
10 mg/L, 100 mg/L, 1000 mg/L	CONTOURS OF EQUAL CONCENTRATIONS OF TRICHLOROETHENE IN MICROGRAMS PER LITER
?	QUERIED WHERE APPROXIMATE OR INFERRED

QUALIFIERS FOR ORGANIC SAMPLES

ND	BELOW INSTRUMENT DETECTION LIMIT
J	INDICATES AN ESTIMATED VALUE
B	INDICATES THE ANALYTE WAS FOUND IN THE ASSOCIATED LABORATORY BLANK

NOTES:

1. BASED ON 1991 SAMPLES OR MOST RECENT AVAILABLE DATA IN 1990 IF MORE THAN ONE SAMPLE WAS COLLECTED THE HIGHEST REPORTED VALUE AND/OR THE VALUE WITHOUT ANY QUALIFIER IS SHOWN.
2. ALL SAMPLES WERE COLLECTED BY GEOTECH, EXCEPT THOSE IDENTIFIED AS JACOBS, WHICH WERE COLLECTED BY JACOBS ENGINEERING IN 1991, AND SPRING 1992.
3. RADIAN CORPORATION REPORTED THAT TRICHLOROETHENE WAS NOT DETECTED IN THE TWO PALUXY AQUIFER MONITOR WELLS DURING 1990 SAMPLING IN THE FLIGHTLINE AREA. (INSTALLATION RESTORATION PROGRAM, STAGE 2, SITE CHARACTERIZATION REPORT, NOVEMBER 1990.)

0 500 1000 2000
SCALE IN FEET

SOURCE: CN GEOTECH, 1993.

PALUXY AQUIFER TRICHLOROETHENE CONCENTRATIONS – 1991
AIR FORCE PLANT 4/CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS

FIGURE 4-6

Project No.: 3932033G-0320-3120	US ARMY CORPS OF ENGINEERS
Date: March 1994	
Drawn By:	ESE Environmental Science & Engineering, Inc.
Checked By:	
Approved By:	

233 57

Figure 4-7	Terrace Deposits, Trichloroethene Concentrations - October, 1993

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

233 58

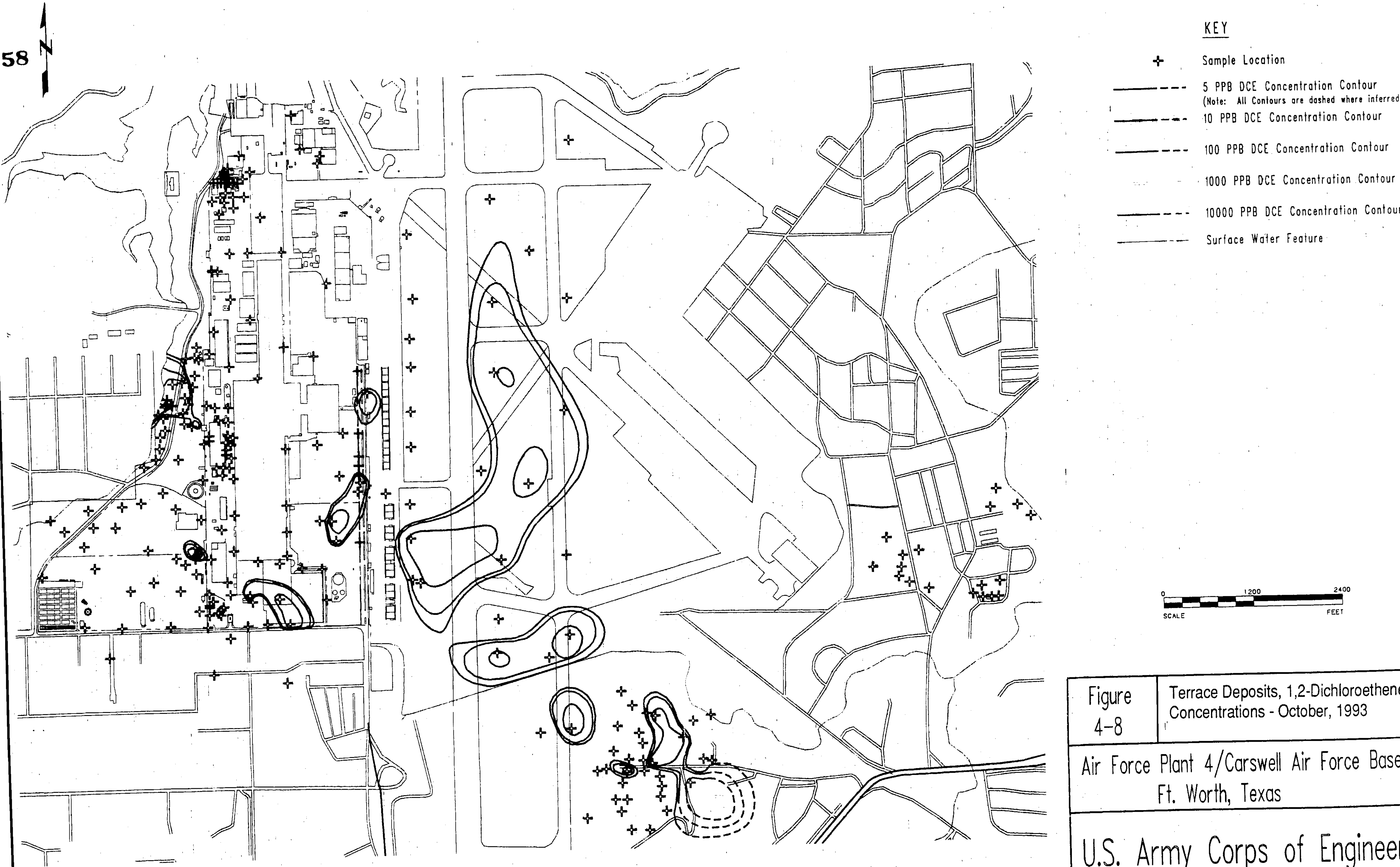


Figure 4-8	Terrace Deposits, 1,2-Dichloroethene Concentrations - October, 1993

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

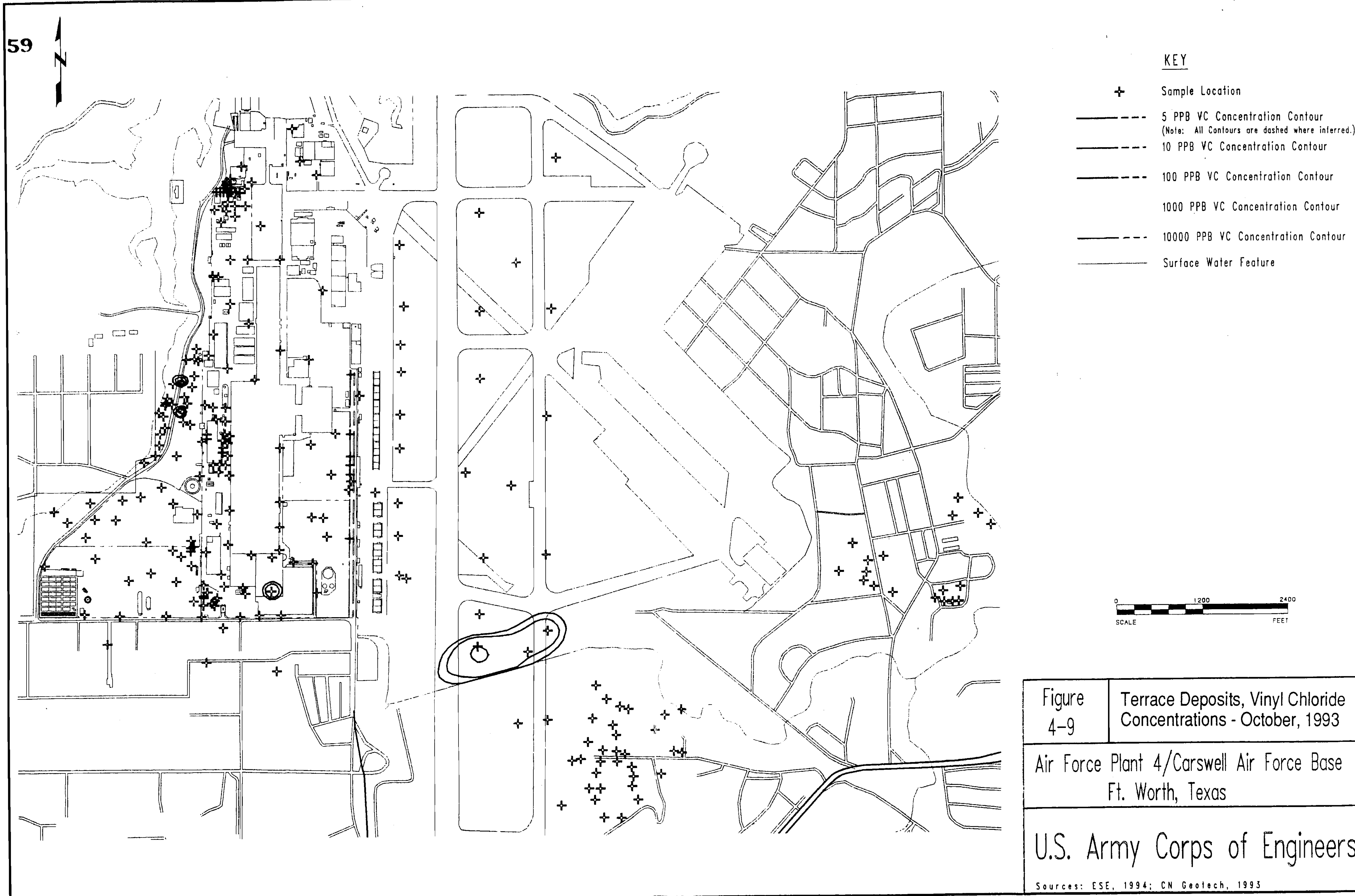


Figure 4-9	Terrace Deposits, Vinyl Chloride Concentrations - October, 1993

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

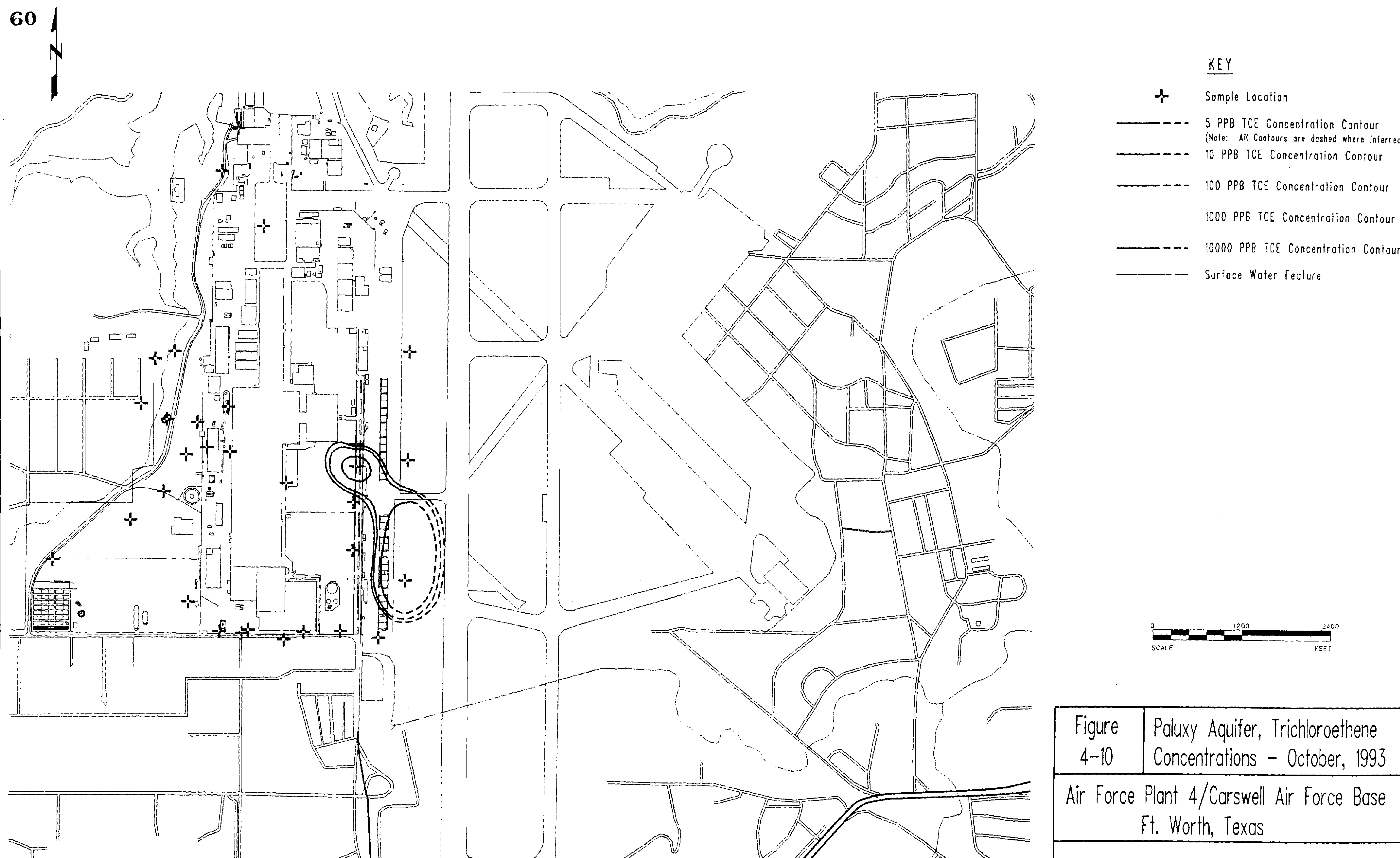


Figure 4-10	Paluxy Aquifer, Trichloroethene Concentrations - October, 1993

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

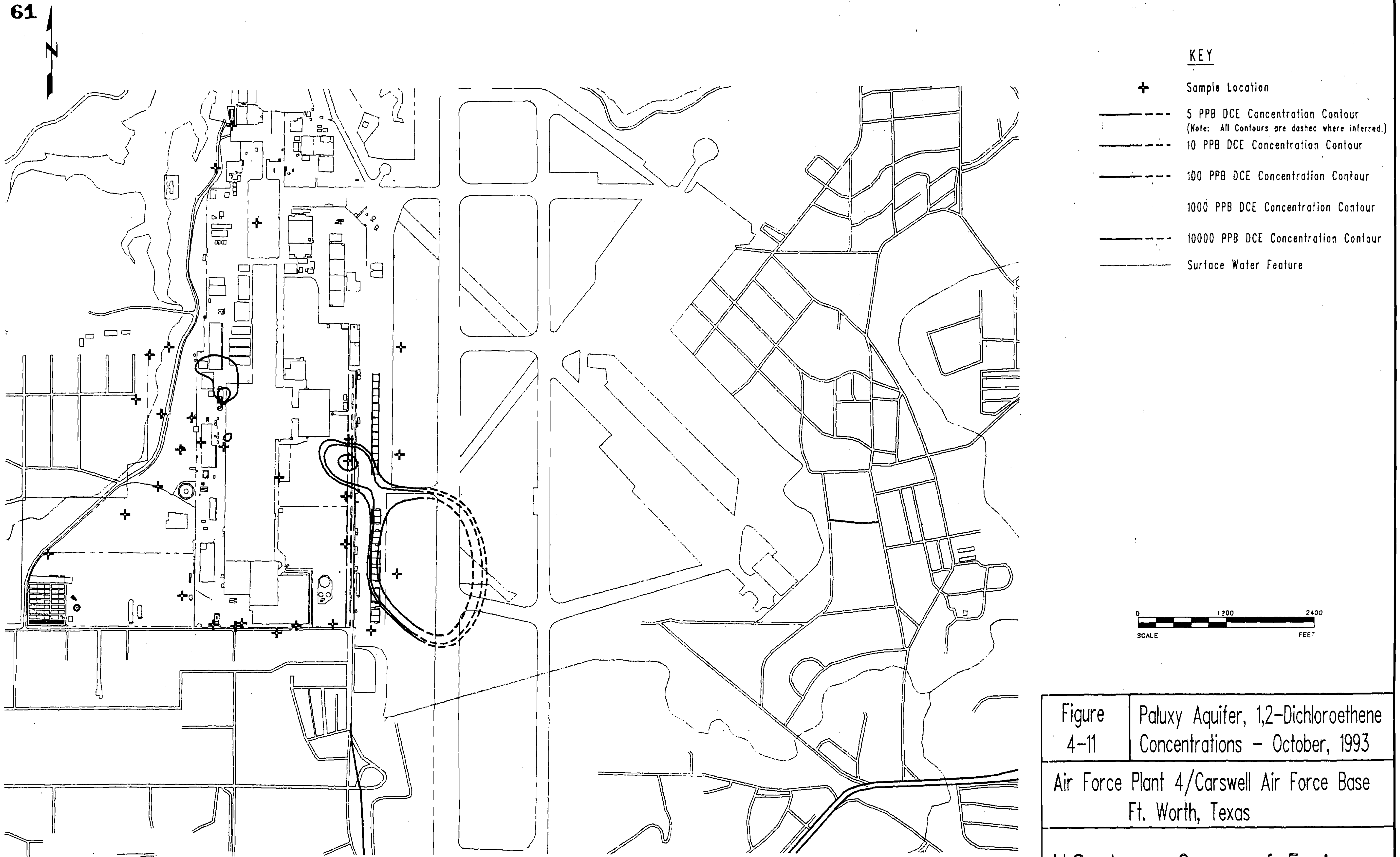


Figure 4-11	Paluxy Aquifer, 1,2-Dichloroethene Concentrations - October, 1993

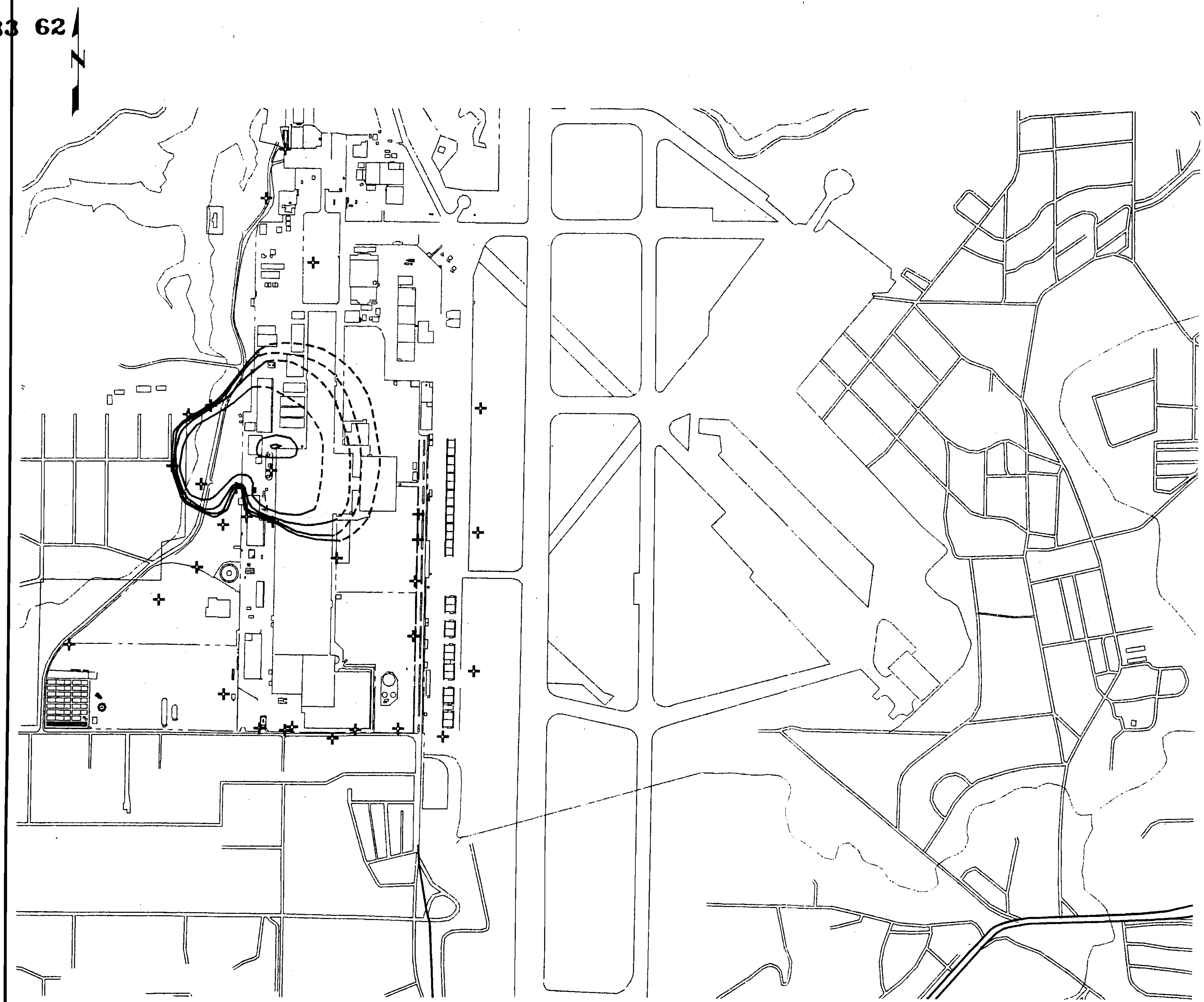
Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

/CARSWELL-AFB/ANALYTEDATA/vc93pal.plt

233 62



KEY

✛ Sample Location

5 PPB VC Concentration Contour
(Note: All Contours are dashed where inferred.)

10 PPB VC Concentration Contour

100 PPB VC Concentration Contour

1000 PPB VC Concentration Contour

10000 PPB VC Concentration Contour

Surface Water Feature

0 1200 2400
SCALE FEET

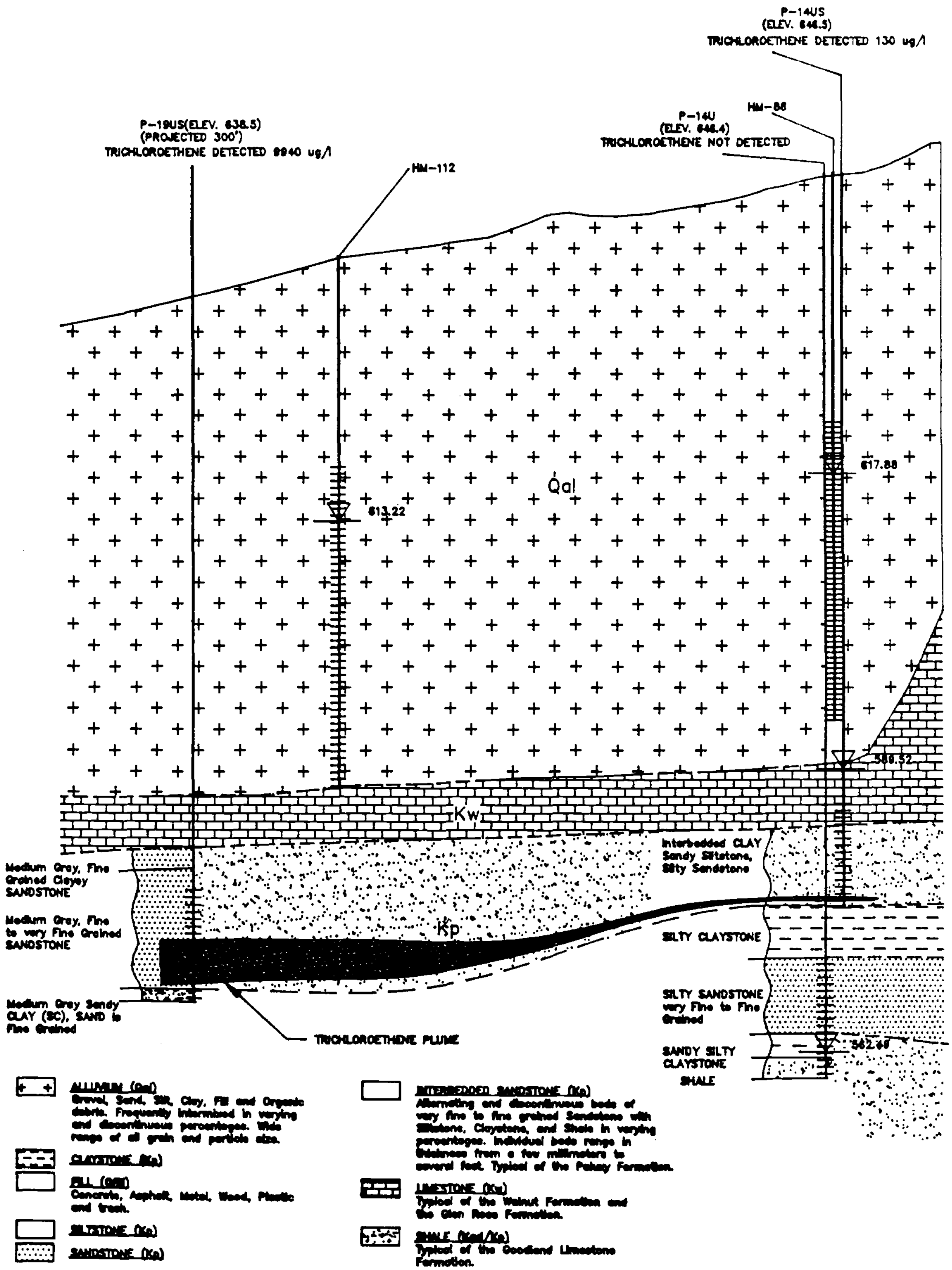
Figure 4-12	Paluxy Aquifer, Vinyl Chloride Concentrations - October, 1993

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

PLOTTED: Feb 24, 1994 – 10:11:14



VERTICAL EXTENT OF TRICHLOROETHENE IN PALUXY AQUIFER - OCTOBER 1993
AIR FORCE PLANT 4/CARSWELL AIR FORCE BASE
FT. WORTH, TEXAS
FIGURE 4-13

Source: ESE, 1994

Project No. :	3932033G-0310
Date :	February 1994
Drawn By :	N.M.D.
Checked By :	M.A.B.
Approved By :	M.J.G.

US ARMY CORPS OF ENGINEERS

ESE Environmental Science & Engineering, Inc.

4.1.2 TCE FREE-PRODUCT MIGRATION: Terrace Deposits

As presented by Chem-Nuclear Geotech (1993), one indicator of TCE in a free-phase dense, nonaqueous-phase liquid (DNAPL) is the presence of TCE in groundwater samples that exceed one percent of the total solubility of TCE (Cohen and Mercer, 1993). Since the solubility of TCE is 1,100,000 micrograms per liter (μg/L) (0.1 percent), groundwater samples collected from monitor wells containing a TCE concentration greater than 11,000 μg/L may indicate that TCE free-product DNAPL is present near that well. Monitor wells located in three different areas of AFP4 have, historically, contained TCE concentrations exceeding 11,000 μg/L. The three areas include Chrome Pit No. 3 (DP12), LF03 (AFP4), and the East Parking Lot (Window Area). TCE product located in DP12 and LF03 are sources for the West and North plumes. The East Parking Lot plume source is the DNAPL free product found under the East Parking Lot and Building 181/182.

The TCE product located in DP12 and LF03 (AFP4) is localized and relatively smaller than the amount of TCE product located in the East Parking Lot. Suspected TCE free product in DP12, using 11,000 μg/L as an indicator, is located near HM-51, F-220, and W-150U. Suspected TCE product, as determined by the 11,000 μg/L indicator, is localized in the area of HM-38, a shallow depression of the bedrock.

The approximate location of free-product DNAPL in the East Parking Lot Area is within the paleochannel located in the Window Area (Figure 4-7). The paleochannel in this area is a preferential pathway for DNAPL migration for two reasons. First, the paleochannel is an incision in the aquitard, which is a topographic low in the bedrock. DNAPL will migrate downward and move downslope into the lowest elevations of the aquitard. Secondly, the deposits within the paleochannel are comprised of a larger diameter of gravel and sands, allowing for a higher transmissivity and a greater intrinsic permeability.

Potential DNAPL extends from Building 181/182 (probable source for TCE product) to the northeast, following the axis of the paleochannel. Analytical data collected in 1989 and 1992 suggest that the extent of DNAPL is terminated near HM-94. However, groundwater analytical data collected in January and June 1993 suggest that the DNAPL plume has migrated from the HM-94 monitor well area. The groundwater samples collected in June 1993 suggest that TCE product has migrated southeast, toward HM-112. HM-112 is located downslope in the paleochannel where the DNAPL was estimated to be present, and TCE concentration detected in HM-112 increases significantly. The groundwater sample collected from HM-112 in June 1993 contained 8,400 μg/L of TCE. This concentration was 220 percent higher than the TCE concentration detected 9 months earlier during the January sampling event. The increase of TCE concentrations over a relatively short time period suggests that TCE free product may be approaching the monitor well HM-112 area.

The analytical data collected during the June 1993 sampling event suggest that an additional pulse of TCE product is migrating from Building 181/182. TCE concentrations detected in two monitor wells (W-159 and HM-88) in and downgradient/downslope of Building 182 have increased between the January and June 1993 sampling events. TCE concentrations detected in W-159, installed within Building 182, have increased by 12,000 μg/L from 31,000 μg/L to 43,000 μg/L. TCE concentrations detected in HM-88, which is installed downgradient within the paleochannel, have increased by 43,700 μg/L from 6,700 μg/L to 50,000 μg/L. The pulse of product may have been released during the reported TCE spill in 1992 (Chem-Nuclear Geotech, 1993).

4.1.3 TCE FREE-PRODUCT MIGRATION: PALUXY AQUIFER

As indicated by analytical data collected in 1992 and 1993, TCE-contaminated groundwater has entered the Paluxy aquifer through a breach in the Goodland-Walnut aquitard in the Window Area. Although groundwater samples collected from Paluxy monitor wells during previous sampling events have indicated that

TCE contamination has affected two areas of the Paluxy aquifer, TCE concentrations detected ranged from nondetect to approximately 2,000 μg/L. Until the installation and sampling of Paluxy monitor well P-19US, the evidence of potential TCE was not substantial; however, high TCE concentrations detected in P-19US suggest that TCE product may be present.

Groundwater samples collected from P-19US (located downgradient of the Window Area) in 1992 sampling events contained TCE concentrations ranging from 8,400 to 8,900 μg/L, which approaches the 11,000 μg/L indicator concentration. The groundwater samples collected during the January 1993 and June 1993 sampling events contained 11,000 μg/L and 9,940 μg/L, of TCE, respectively, suggesting that free product is in the vicinity.

4.2 CONTAMINANT FATE AND TRANSPORT

4.2.1 CONTAMINANT PROPERTIES

Fate and transport of a contaminant within an aquifer system depends on specific physical and chemical properties of chemical compounds. To closely approximate the rate of transport and the fate of contaminants, certain contaminant chemical and physical properties must be incorporated in the transport and fate calculations. The most important physical properties used in the approximation of contaminant fate and transport are the following:

1. Solubility,
2. Density, and
3. Carbon/water coefficient.

4.2.1.1 Solubility

Solubility is defined as the maximum amount of a substance that can be dissolved in a solvent at a given pressure and temperature. The contaminant concentration in groundwater that exceeds the solubility of the contaminant is referred to as pure phase product. The solubility of TCE is 1,100 milligrams per liter (mg/L) or 1,100,000 μg/L (EPA, 1986).

4.2.1.2 <u>Density ρ</u>

Density (specific gravity) is the mass of a compound per volume at a specified temperature and pressure. Compounds with a density of greater than 1.00 g/mL sink in water (DNAPL), and compounds with a density less than 1.00 will float on water [light nonaqueous-phase liquid (LNAPL)]. The density of TCE is 1.46, placing TCE into the DNAPL group.

4.2.1.3 <u>Carbon/Water Coefficient (K_{oc})</u>

The K_{oc} is the ratio of the mass of compound absorbed per unit mass of carbon in the porous media to the concentration of the compound at equilibrium. K_{oc} values are used to determine the amount of solute that will be absorbed by carbon existing in the porous media. The K_{oc} value for TCE is 126.

4.2.2 CONTAMINANT FATE AND TRANSPORT: NUMERICAL METHODS

Contaminant fate and transport in groundwater depends on the following processes:

1. Advection,
2. Sorption,
3. Diffusion, and
4. Dispersion.

The primary processes controlling contaminant transport in the aquifer systems studied during this investigation are advection and sorption. Since the groundwater flow velocity is relatively fast beneath the study area, diffusion and dispersion are not the major contributors of TCE transport in the Terrace Deposits. Advection is the process at which contaminants are transported by the motion of groundwater, which is caused by the differences in pressure, temperature, or density (Fetter, 1988). The primary force causing advection in groundwater is hydraulic gradient. Advection is approximated by using the average linear velocity of groundwater in the aquifer systems (Equation 3-1).

Sorption is the partitioning of the contaminant between liquid and solid phases of the porous media. The term includes processes such as ion-exchange, adsorption, colloid filtration, reversible precipitation, and irreversible mineralization. Absorption is the most dominant process of sorption. Absorption is defined as the attraction adhesion of a layer of ions from an aqueous solution to the solid mineral surfaces with which it is in contact (Fetter, 1988). Absorption is generally viewed as a reversible, equilibrium process and can be quantitatively described as a isotherm. An isotherm is a relationship between the contaminant concentration in the liquid and the solid phases. Commonly used isotherms are the Freundlich and Languimer Isotherms. Absorption can be numerically defined in the following equation:

$$S = K_d \; X \; C^a \qquad \text{4-1}$$

Where: S = mass of solute sorbed per bulk density of dry soil;
K_d= distribution coefficients, dependent on solute species; and
C^a= concentration of solute in the liquid phase.

Note: if Freundlich isotherm is used a=1

K_d is a function of the sorptive properties of the soil and properties of the individual compounds. K_d can be numerically defined as the following equation:

$$K_d = f_{oc} \; X \; K_{oc} \qquad \text{4-2}$$

If solute is being sorbed on to soil particles, velocity of solute movement, relative to the velocity of groundwater, decreases. The decrease in solute movement is defined as retardation. The degree of retardation is defined as R, which is the retardation factor. R can be defined numerically by the following equation:

$$R = 1 + [\; \rho_b \; X \; K_d/\eta_e \;] \; (Fetter, 1988) \qquad \text{4-3}$$

Where: R = retardation factor (dimensionless),

ρ_b = bulk density of aquifer material [grams per cubic centimeter (g/cm^3)]

K_d = distribute coefficients (dimensionless)

n_e = effective porosity (dimensionless)

(Fetter, 1988)

A retardation factor of 1 means that the solute is not retarded, and the velocity of solute movement is equal to the velocity of groundwater movement.

To determine the velocity of solute movement in groundwater under sorption processes the following equation is used:

$$V_s = V_g/R \tag{4-4}$$

Where: V_s = velocity of the solute (ft/day),

V_g = Average linear velocity of groundwater (Equation 3-1) (ft/day), and

R = retardation factor (dimensionless) (Fetter, 1988).

The retardation values were substituted into Equation 4-4 to determine the linear flow velocity of TCE within the aquifers.

4.3 TCE MIGRATION: Terrace Deposits

This section presents the approximate rates of TCE flow within the Terrace Deposits beneath AFP4 and CAFB. Despite the size and inhomogeneity of the Terrace Deposits and due to the lack of fraction of organic carbon, an estimate for fraction of organic carbon will be used for the Terrace Deposits system. Due to the approximation of the f_{oc} on a aquifer-wide basis, TCE will have the same retardation factor throughout the entire Terrace Deposits.

Prior to approximating the flow velocity, the retardation factor for TCE in the Terrace Deposits was calculated. The following values were substituted into Equations 4-2 and 4-3 to determine the retardation factor:

K_{oc}	=	126 mL/g (EPA, 1986),
f_{oc}	=	0.017 (Mercer, 1988; Jury et al., 1983),
ρ_b	=	1.86 g/cm^3 (Chem-Nuclear Geotech, 1993), and
n_e	=	0.30 (Fetter, 1988).

The retardation for TCE in the Terrace Deposits, as calculated by Equation 4-4 is, 14. The retardation factor of 14 will be used to determine the flow velocity of the TCE plume in the Terrace Deposits.

The calculations to determine the flow velocity of TCE movement in the East Parking Lot Plume were based on hydrogeologic information gathered from previous studies conducted in the CAFB East and Flightline Areas. The average groundwater flow velocities calculated in Section 3.0 (Tables 3-3 and 3-4) were substituted in Equation 4-4 to calculate the TCE flow velocity. Due to significant figures, two groundwater flow velocities, one calculated for the CAFB East Area and one CAFB Flightline Area, substituted into Equation 4.4 produced the same value for TCE flow velocity. The estimated distances of TCE migration for the East Parking Lot plume over time are shown in Table 4-1. The model assumed dissolved-phase TCE. The extent of the East Parking Lot plume, over 5, 10, and 20 years, without remediation, is approximated in Figure 4-14.

The velocity of TCE movement in the West plume, as determined by Chem-Nuclear Geotech ranges from 0.006 to 0.48 ft/day. The retardation factor for TCE in the Terrace Deposits used by Chem-Nuclear Geotech was 14. TCE migration distances over time are summarized in Table 4-1.

Table 4-1. TCE Migration for East Parking Lot, West, and Paluxy Aquifer Plumes

Site	TCE Flow Velocity (ft/day)	5-Year Distance (ft)	10-Year Distance (ft)	20-Year Distance (ft)
East Parking Lot	0.0093	16.95	33.89	67.79
West Plume				
Minimum	0.006	11.0	22.0	44.0
Maximum	0.48	876	1,752	3,504
Paluxy Aquifer				
Minimum	0.19	60.28	120.5	241.9
Maximum	1.06	346	693.5	1,387

Source: ESE.

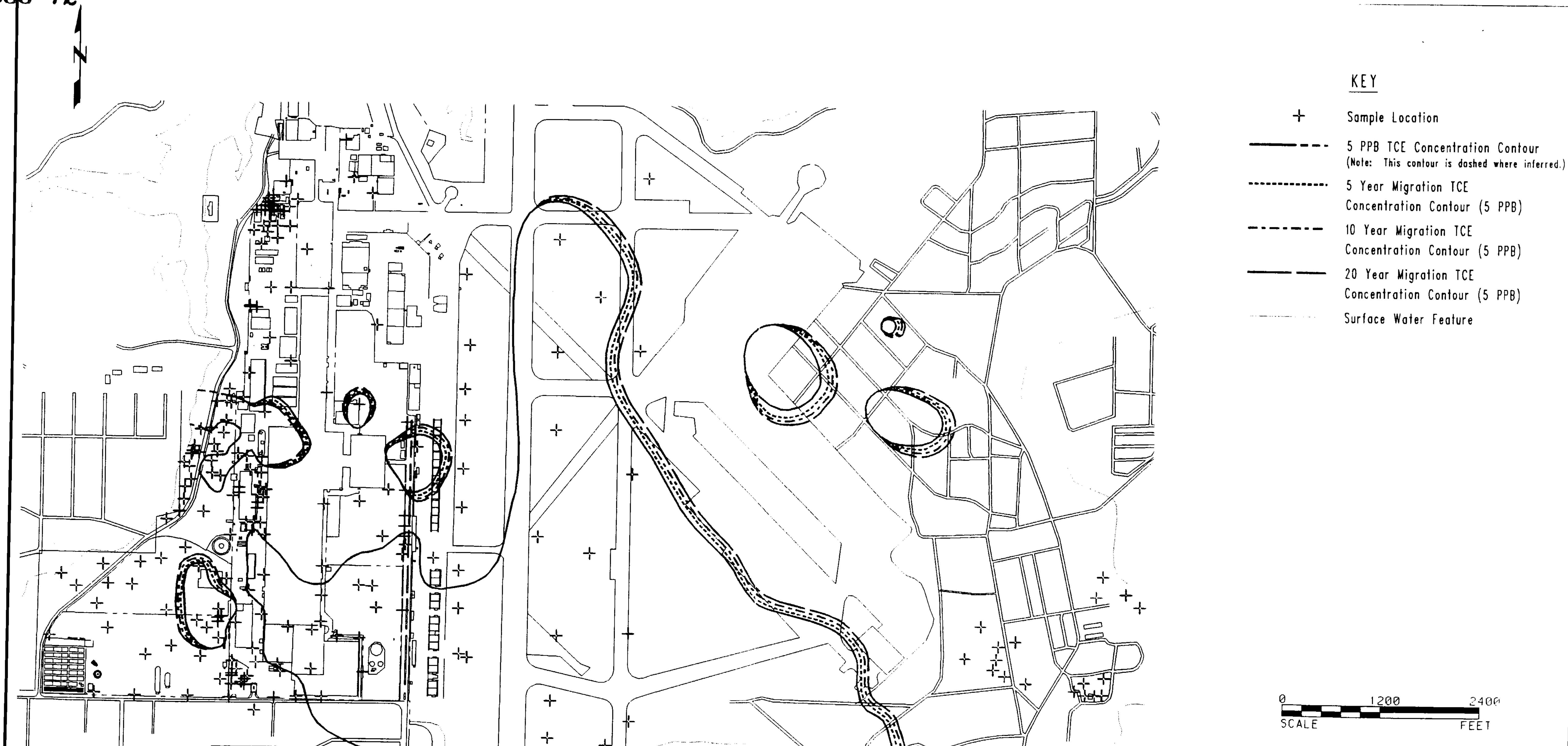


Figure 4-14	Extent of Trichloroethene Migration in Terrace Deposits Over Time

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

The higher values represent a steeper hydraulic gradient in the paleochannel located beneath LF01 and LF03. The flow velocity of TCE indicates relatively rapid contaminant migration to the west and southwest in the LF03 area, suggesting that TCE-contaminated groundwater may be flowing into Meandering Road Creek. Surface water samples and toxicity studies indicate that Meandering Road Creek is being impacted by the contaminated Terrace Deposits groundwater in this area (Chem-Nuclear Geotech, 1992). Due to the presence of Meandering Road Creek, it is unlikely that TCE in the West plume will migrate to the west bank of Meandering Road Creek. The extent of the West plume, over 5, 10, and 20 years, without remediation, is shown in Figure 4-14.

4.4 TCE MIGRATION: PALUXY AQUIFER

This section presents the approximate rates of TCE flow within the Paluxy aquifer beneath AFP4 and CAFB. Soil samples collected from the Paluxy Formation were analyzed for fraction of organic carbon, which will be used for the Paluxy aquifer system. Since one f_{oc} value will be used in the retardation factor calculation, TCE will have the same retardation factor throughout the entire Paluxy aquifer. Prior to the approximation of the flow velocity, the retardation factor for TCE in the Paluxy aquifer was calculated. The following values were substituted into Equations 4-1, 4-2, and 4-3 to determine the retardation factor:

K_{oc} = 126 mL/g (EPA, 1986),
f_{oc} = 0.006 (Huffman Laboratories, 1991),
P_b = 1.86 g/cm^3 (Chem-Nuclear Geotech, 1993), and
n_e = 0.27 (Fetter, 1985).

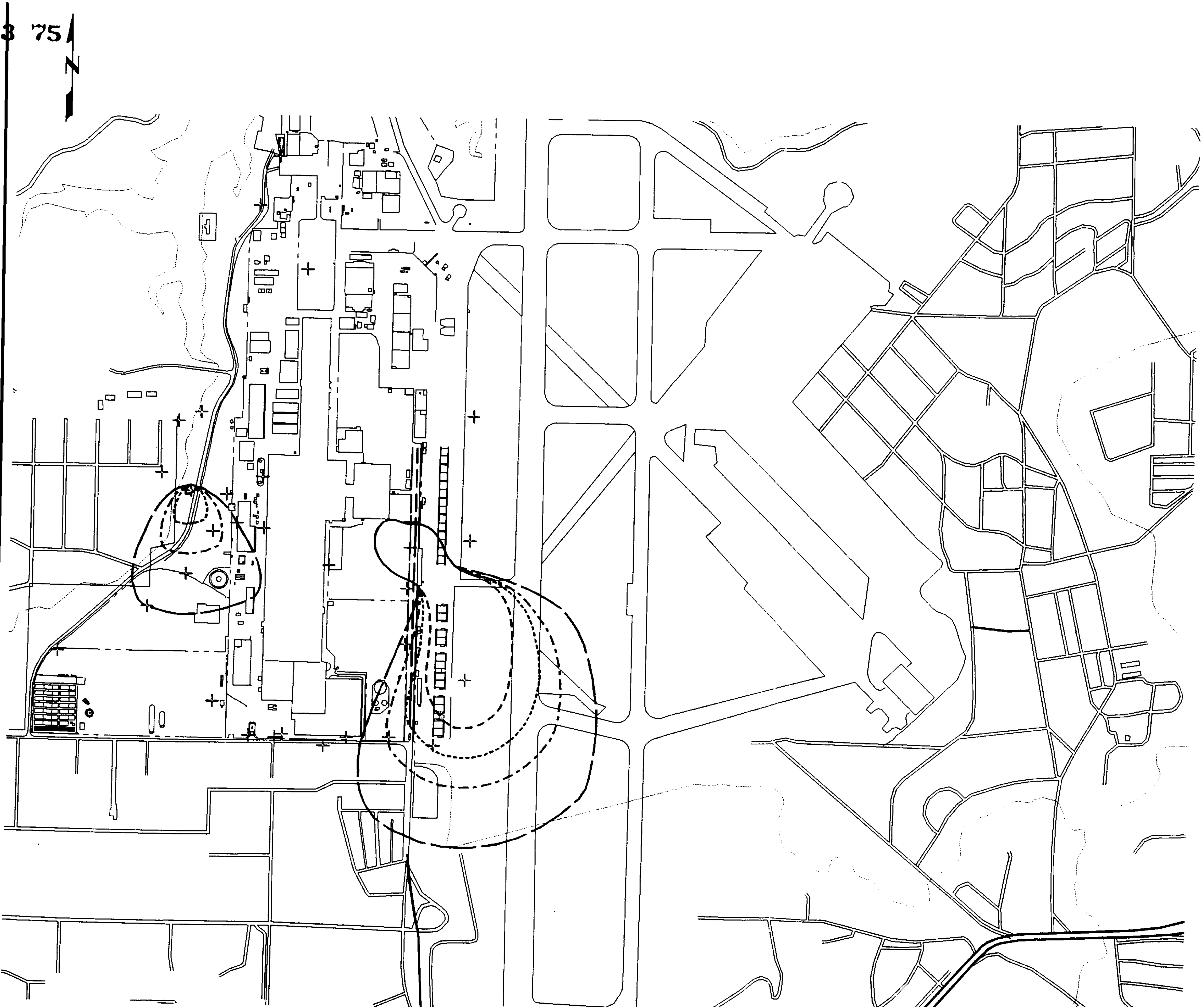
The retardation for TCE in the Terrace Deposits, as calculated by Equation 4-3, is 5.69. Substituting the retardation factor and the average Paluxy groundwater flow velocities (Tables 3-8 and 3-9) into Equation 4-4, the flow velocities for TCE within the Paluxy aquifer are 0.033 and 0.19 ft/day. The parameter that created a wide disparity between the TCE flow velocities is the value for the average groundwater velocity substituted into Equation 4-4. The TCE flow velocity of 0.033 ft/day was calculated by the average Paluxy groundwater flow velocity as determined by slug tests performed in four Paluxy monitor wells located in the southwest side of AFP4. The TCE flow velocity of 0.19 ft/day was calculated using the average Paluxy groundwater flow velocity as determined by pump tests performed in 10 Paluxy monitor wells located near the Window Area at AFP4. The estimated distance of TCE migration in the Paluxy, with no change in the gradient, based on an isotropic and homogeneous aquifer for 5, 10, and 20 years, is summarized in Table 4-1.

For a conservative approximation, the higher flow velocity was used for estimating TCE migration. The extent of TCE migration in the Paluxy aquifer without remediation is shown in Figure 4-15.

A comparison of the calculated flow rate to the past observed flow rate is not possible because the exact location of the point source(s) of TCE contamination (in this case, the breach in the aquitard) is approximated. Also, the approximate date of contaminant introduction to the Paluxy aquifer is unknown because the introduction of TCE to the Paluxy depends on the time of TCE migration from the point source of TCE to the estimated location of the breach in the Terrace Deposits aquitard.

4.5 NUMERICAL MODEL SUMMARY AND LIMITATIONS

The TCE migration velocity in the Terrace Deposits, as calculated using the information previously listed, ranged from 0.006 to 0.0093 ft/day. The model assumed dissolved-phase TCE. The calculated flow velocity for TCE within the Paluxy aquifer ranged from 0.033 to 0.19 ft/day. The equations used for calculating the flow rates are basically the same equations used in more complicated computer models; however, the equations only reflect approxima-



KEY

+ Sample Location

5 PPB TCE Concentration Contour (Note: This contour is dashed where inferred.)

5 Year Migration TCE Concentration Contour (5 PPB)

10 Year Migration TCE Concentration Contour (5 PPB)

20 Year Migration TCE Concentration Contour (5 PPB)

Surface Water Feature

0 1200 2400
SCALE FEET

Figure 4-15	Extent of Trichloroethene Migration in Paluxy Aquifer Over Time

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

tions of hydrogeologic parameters and aquifer systems that are assumed to be isotropic and homogeneous.

To determine the observed rate of TCE migration in the Terrace Deposits, the distance of the travel was divided by the amount of time AFP4 has been in service (1942 to 1992). Since AFP4 was put into service approximately 50 years ago, the distance between Building 181/182, the probable main source of TCE contamination, and HM-121, the farthest extent of Building 181/182 TCE, was divided by 50 years.

The observed rate of TCE movement in the East Parking Lot plume of the Terrace Deposits is approximately 0.30 ft/day. The difference in the rate of TCE movement can be attributed to a variety of factors, which were not included in the numerical model used for this study.

Due to the limitations of the numerical model, the thickness of the Terrace Deposits was not included as a factor. The thickness of the Terrace Deposits depends on the topography of the competent bedrock located below the alluvial material. Since TCE is a DNAPL, the migration path chosen by TCE will be downslope on the top of the lowest points of the confining layer. Conversely, TCE will not flow over significant topographic highs in the top of the confining layer. Instead, the TCE will migrate to the lowest point or pool until completely transported by the advection of groundwater. Due to the physical properties of TCE, the topography of the confining layer is significant to TCE fate and transport.

The simple estimations of TCE transport do not include the change of hydrogeologic properties caused by the larger-diameter sand and gravels located in the paleochannels beneath the study areas. These gravel and sand deposits represent areas of faster groundwater flow velocity and preferential flow paths of TCE contamination.

The point source of TCE contamination detected throughout the East Parking Lot area may not be Building 181/182. The point source for the majority of the contamination detected in the Terrace Deposits and Paluxy aquifer may consist of TCE free-product pulses that can be characterized as a slow moving source of free TCE. As the TCE product flows downslope along the axis of the paleochannel, dissolved TCE may be advected in the direction of groundwater flow, thus creating a mobile secondary point source for dissolved TCE. Additionally, residual TCE product will be left in the path of the migrating TCE product plume, acting as a source for dissolved TCE. As discussed previously, the source of TCE product detected in the Paluxy aquifer was the TCE product that migrated downward from the Terrace Deposits through the breach in the aquitard to the Paluxy. The moving source factor was not reflected in the simple model used for this study.

The parameters used for calculating the retardation factors were approximated from references and not from actual laboratory results. Specifically, a major contributor to the retardation factor is the fraction of organic content for the porous media. A small deviation from the estimated f_{oc} and the actual f_{oc} for the aquifer material can change the retardation factor significantly.

Additional site-specific information pertaining to porosity, density, hydraulic conductivity, hydraulic gradient, and bedrock topography would develop a more accurate model for the fate and transport of TCE beneath the study area.

Additional site-specific information, incorporated into a computer model, will develop a more accurate description of contaminant fate and transport at the study area. Groundwater flow models incorporating site-specific data will be able to accomplish the following:

1. Approximate groundwater velocities (as dependent on aquifer thickness),
2. Capture zones for recovering wells,

3. Stagnation points in groundwater flow,
4. Vertical flow between the Paluxy and Terrace Deposits through the Window Area,
5. Groundwater flow in the Paluxy aquifer,
6. Vertical flow between Paluxy aquifer zones, and
7. Transport of groundwater to surface water.

Fate and transport models, incorporating site-specific information, will approximate contaminant transport caused by dispersion, advection, diffusion, the degradation and transformation of TCE and TCE degradation products, and the vertical transport of TCE from the Terrace Deposits to the Paluxy through the Window Area.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The groundwater contamination below AFP4 and CAFB has been well documented; however, due to the size and complexity of the contaminant plume, certain data gaps are present. During previous studies, four plumes were detected under AFP4 and CAFB, three plumes were detected in the Paluxy aquifer (North Plume, West Plume, and East Parking Lot Plume), and one plume was detected within the Paluxy aquifer (in the vicinity of the Window Area). The vertical extent of the plumes have been determined, with the exception of the East Parking Lot and Paluxy aquifer plumes. The downgradient extent of the East Parking Lot plume, in the Paluxy aquifer flow system and the Paluxy Formation, has not been determined. Since TCE may be present in free-product state in the Paluxy aquifer and the Paluxy aquifer, additional subsurface investigations are needed to implement more effective remedial actions. Due to the difficulty of locating DNAPL with monitor wells, alternative technologies should be considered to locate DNAPL in the Terrace Deposits. Specifically, chemical tracers and geophysical methods should be considered to identify DNAPL locations. However, using geophysical methods to determine the most likely collection areas of TCE DNAPL (topographic lows in the top of the aquitard), monitor wells may be installed in areas where DNAPL has accumulated in the aquitard depressions.

ESE recommends that the following subsurface investigations be conducted to define the horizontal and vertical extent of contamination in the Paluxy aquifer flow system and the Paluxy aquifer and to characterize hydrogeologic properties of the aquifer systems:

1. Geophysical surveys to determine the topography of competent bedrock (Goodland-Walnut aquitard);
2. Paluxy aquifer investigation--hydrogeologic studies and installation, development, and sampling of Paluxy aquifer monitor wells within paleochannels and/or beyond areas of known contamination;

3. Paluxy aquifer investigation--well installation and sampling to determine extent of contamination in Paluxy aquifer and hydrogeologic parameter investigation.
4. Computer modeling study--completion of groundwater modeling studies conducted in the Paluxy aquifer and Paluxy aquifer to approximate groundwater flow and contaminant fate and transport.

5.1 GEOPHYSICAL INVESTIGATION

To determine the vertical and horizontal extent of the TCE contamination present in the Paluxy aquifer flow system, ESE recommends that a geophysical survey be conducted in specific areas in the East Parking Lot plume. This survey will determine the location and size of paleochannels and topographic lows in the aquitard that may be present beneath AFP4 and CAFB. The paleochannels, which are preferential pathways of contaminant migration, need to be delineated in the downgradient edge of the plume to determine possible contaminant migration pathways. Specific information pertaining to the location and size of topographic lows in the top of the Goodland-Walnut aquitard is required to delineate possible collection points for dissolved and free-product TCE. Additional information collected from the geophysical survey will be used to determine the thickness of the Goodland-Walnut aquitard to determine if additional pathways of downward migration to the Paluxy aquifer exist.

Geophysical surveys should be conducted on the east, south, and north sides of the East Parking Lot plume. After reviewing different geophysical methods, ESE recommends that seismic refraction or electromagnetics be used for the geophysical surveys. The geophysical surveys should be conducted east of the East Parking Lot area in the flightline area and along Taxiway 191 to determine the topography of competent bedrock (Figure 5-1) on the north edge of the East Parking Lot plume. Geophysical data should be correlated with soil boring and monitor well logs.

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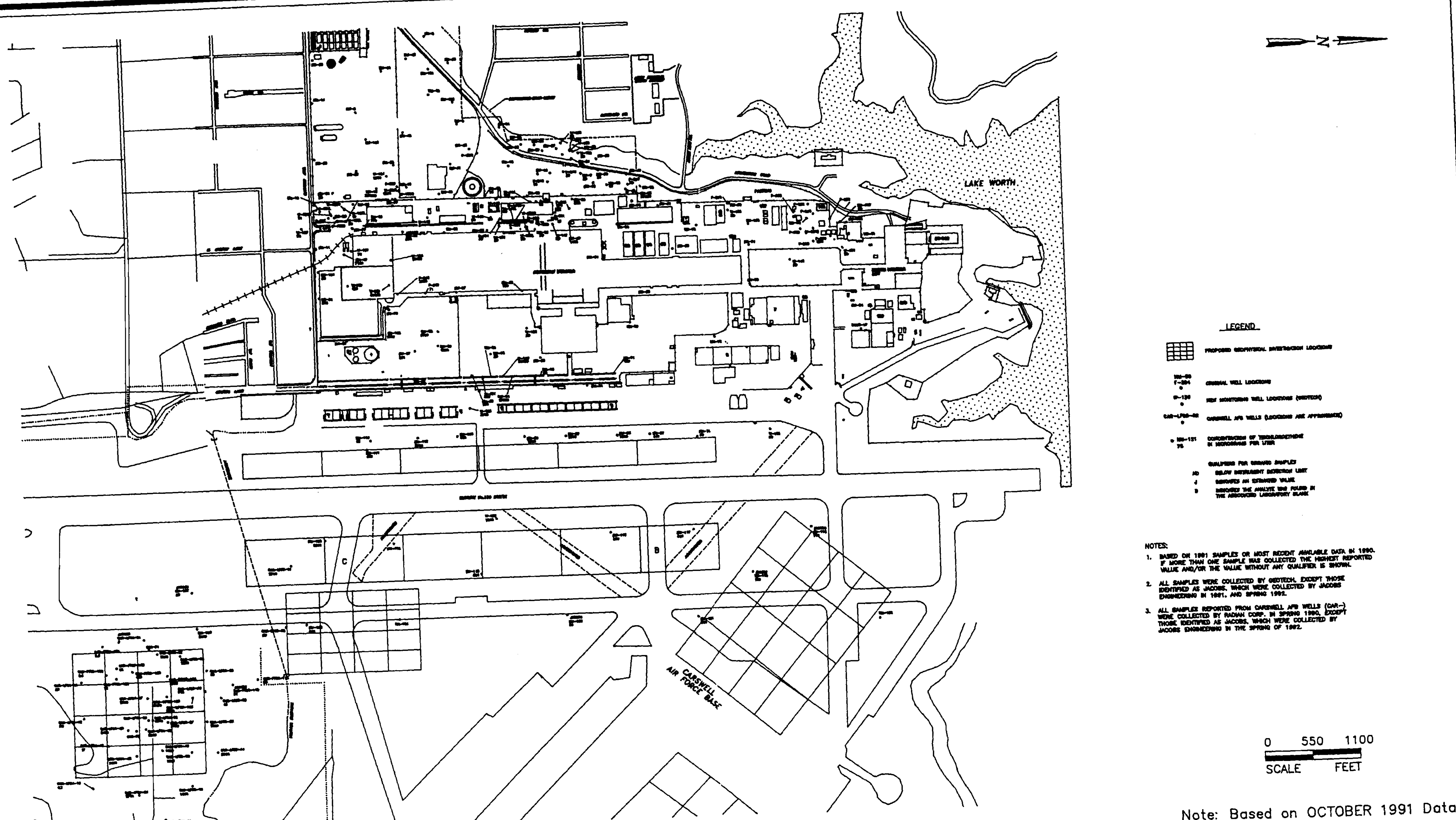


Note: Based on OCTOBER 1991 Data.

Figure 5-1
PROPOSED GEOPHYSICAL INVESTIGATION LOCATIONS

Source: ESE; CN GEOTECH.

Environmental Science & Engineering, Inc.

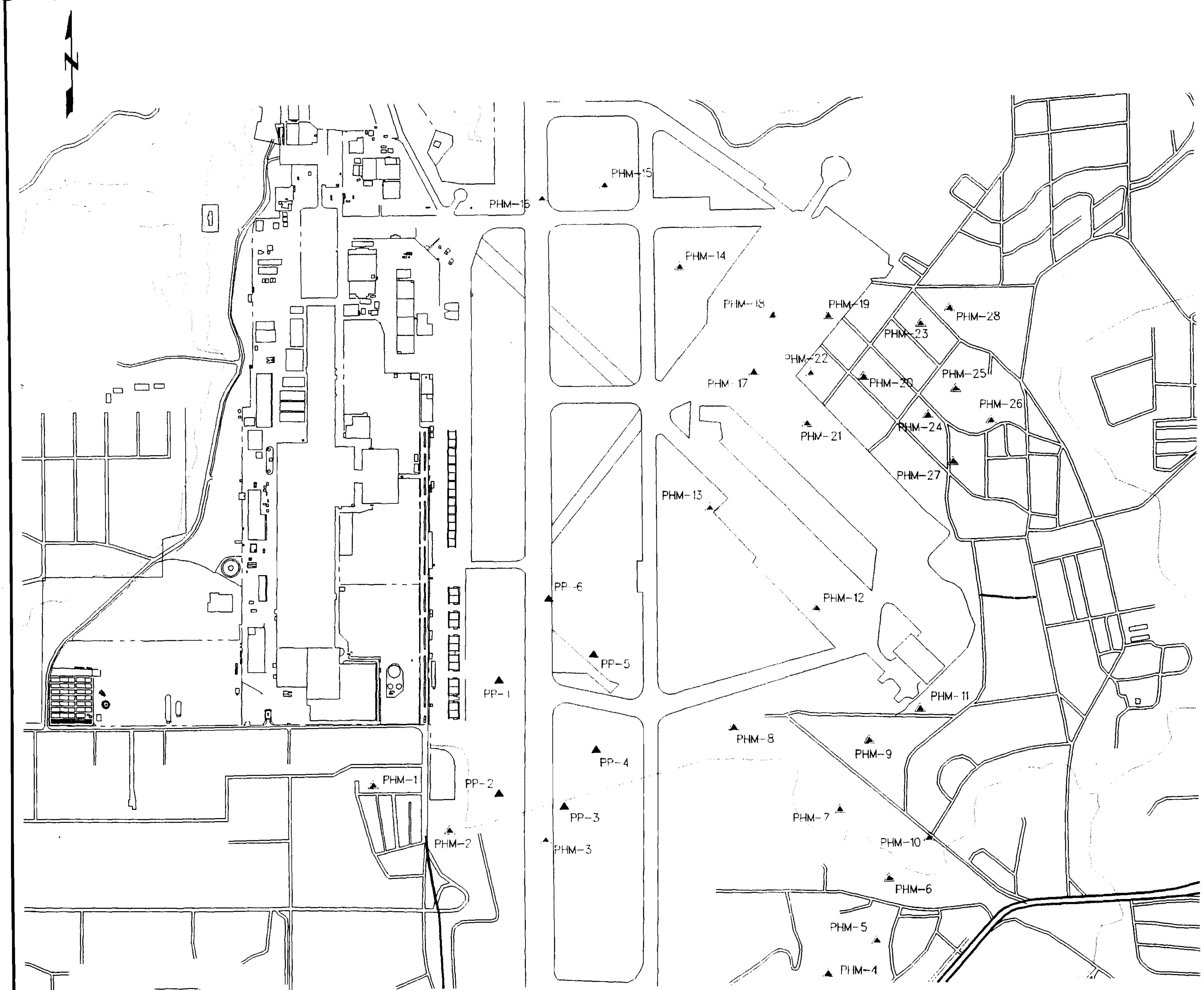
5.2 TERRACE DEPOSITS AQUIFER INVESTIGATION

After the results of the geophysical survey have been evaluated, a shallow monitor well installation program should be initiated. Monitor wells should be installed to determine the vertical extent of contamination in the Paluxy aquifer flow system on the north, east, and south sides of the plume. Monitor wells, at a minimum, should be constructed beyond the areas of known groundwater contamination, specifically beyond the eastern, northern and southern edge of the plume (Figure 5-2). Exact locations of Terrace Deposits monitor wells should be based on the latest information available. Additionally, monitor wells should be installed in areas of topographic lows in the bedrock as determined by geophysical data (possible paleochannels) to determine groundwater quality and hydrogeologic characteristics.

Prior to monitor well installation, soil samples should be collected and submitted for laboratory analysis. Soil samples should be collected from the screened interval for each respective monitor well. The soil samples should be analyzed for the fraction of organic content, effective porosity, density, and permeability. Slug tests should be performed in the monitor wells to determine hydraulic conductivity at the farthest extent of the plume. Results of the laboratory analysis and slug test will then be used for TCE migration studies.

5.3 PALUXY AQUIFER INVESTIGATION

A Paluxy monitor well installation program should be initiated to determine the vertical and horizontal extent of contamination in the Paluxy aquifer. Specific emphasis should be placed in the area of Paluxy well P-19US. TCE concentrations detected in P-19US suggest that TCE product may be present in the Upper Paluxy Sands. At a minimum, ESE recommends that at least five Paluxy monitor well suites (consisting of monitor wells installed within the Upper Sand, Upper, and Middle Paluxy Formations) be installed to determine the horizontal and vertical extent of contamination. Proposed Paluxy well locations are identified in Figure 5-2; however, the exact locations of new Paluxy wells



KEY

▲ PHM-1 Proposed Terrace Deposits Monitor Well

▲ PP-1 Proposed Paluxy Monitor Well Nest (Upper Sand, Upper and Middle Paluxy Zone)

Surface Water Feature

0 1200 2400
SCALE FEET

Figure 5-2	Proposed Monitor Well Locations

Air Force Plant 4/Carswell Air Force Base
Ft. Worth, Texas

U.S. Army Corps of Engineers

Sources: ESE, 1994; CN Geotech, 1993

should be based on the latest data available. Additional Paluxy monitor wells should be installed within areas, as shown by geophysical data, where the Goodland-Walnut Formation aquitard is thin and/or absent.

To determine hydrogeologic characteristics of the Paluxy aquifer, additional aquifer tests should be performed. Slug tests should be performed on all newly installed Paluxy monitor wells to determine hydraulic conductivity in the three levels of the Paluxy aquifer. Due to the complexity of the Paluxy aquifer, additional data are required to determine the hydrogeological relationships between the Upper Sand, Upper, and Middle Paluxy aquifer levels. To define the hydrogeological relationships within the Paluxy aquifer, a series of pump tests should be performed in all of the newly installed Paluxy monitor wells. The pump tests will determine and define the extent of hydrogeologic communication between the separate aquifer levels. The information collected from the pump test will be used for calculating contaminant migration in the vertical and horizontal directions within the separate levels of the Paluxy aquifer. Additionally, drawdown information collected as a result of the pump tests will be used to design capture zones and recovery well locations required for the groundwater remediation system.

Rock and/or soil samples of the Paluxy aquifer should be collected prior to monitor well installation. The samples should be collected from the same depth as the screened interval of the monitor well and submitted for laboratory analysis. The soil samples should be analyzed for fraction of organic content, effective porosity, density, and permeability. The analytical results will be used for the calculation of TCE fate and transport within the respective areas of the Paluxy aquifer.

5.4 GROUNDWATER MODELING STUDY

Computer models should be used to approximate groundwater flow and contaminant fate and transport in the Paluxy aquifer and Paluxy aquifer.

Complicated computer models are needed due to the amount of heterogeneity and anisotropy present in the aquifer systems. The computer models should be able to account for changing physical properties throughout the aquifer systems, which will impact various parameters controlling groundwater flow and contaminant fate and transport.

The groundwater modeling study should be conducted according to the following modeling protocol:

1. Define the purpose,
2. Develop a conceptual model,
3. Select code (mathematical model),
4. Parameter resolution (model input),
5. Model calibration,
6. Model verification,
7. Prediction (results),
8. Presentation of results, and
9. Model audit.

After the results of the models are calculated, the results should be compared to field conditions. Certain parameters can be changed to create a more accurate model before the final model results are used for large-scale remedial design.

Two different model types, consisting of a groundwater flow model and particle tracking model, should be used. The groundwater models should consist of 3-D finite difference models or finite element models with a governing equation including all parameters that control groundwater flow and contaminant fate and transport.

Groundwater flow models (e.g., MODFLOW and PLASM) are used to approximate groundwater flow under certain conditions. Groundwater flow models can be used to approximate the vertical flux of groundwater between the

Paluxy aquifer and Paluxy aquifer through the Window Area. Vertical flow in the Paluxy between the Upper Sand and other Paluxy zones can be approximated. The flow models will be used to predict the most efficient recovery well pump rates to create the capture zones needed for groundwater remediation.

Particle tracking models (e.g., MODPATH and PATH3D) are used to approximate the contaminant fate and transport. The particle tracking models will accurately predict contaminant flow under advection, sorption, dispersion, diffusion, transformation, and decay. Using site-specific data collected during the monitor well and geophysical studies, the model will accurately predict fate and transport of TCE and the transformation of TCE to TCE degradation products. The information provided by the particle tracking model will be used during the remediation phase of the IRP.

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